FINAL DRAFT

REMEDY REPORT

OPERABLE UNIT NO. 3 - SWMU 199

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

ENVIRONMENTAL RESTORATION PROGRAM

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REVIEWED FOR CLASSIFICATION/UCNI
By F. J. Curran U-NU
Date 5-9-91

RFPalp.199 *10/24/90*

FOREWORD

This document provides a qualitative evaluation of the overall effectiveness of the ongoing and partially completed court-ordered remediation of lands, known as Solid Waste Management Unit (SWMU) 199, in the vicinity of the U.S. Department of Energy (DOE) Rocky Flats Plant (RFP). These lands were contaminated with low levels of plutonium as a result of past activities at the RFP.

This evaluation report is prepared primarily to fulfill a requirement of the draft Interagency Agreement (IAG) which incorporates the terms of the Settlement Agreement of July 1985 between the DOE and the affected landowners.

The required actions under the IAG are: "Submit a report detailing the history of the remedy ordered by the U.S. District Court pursuant to the land owner's suit settled July 10, 1985, the implementation of the remedy, and the effectiveness of the remedy. Within this report include a health assessment identifying the public health risk associated with potential exposure to the public prior to completing any site remediation, during implementation of the remedy, and after completion of the Settlement Agreement imposed remedy. This report must detail the effectiveness of the remedy and the risks associated with a no action alternative, as well as detailing the risks associated with plausible exposure during implementation of the remedy and after completion of the remedy."

The available data are not of sufficient quality to support a rigorous quantification of the human health risks as required by the IAG. Therefore, at this time, a qualitative evaluation is provided. The results presented in this report will be used by the DOE as part of the scoping activities for the remedial investigation (RI) workplan to be prepared for SWMU 199 under the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Data that will be acquired in the RI sampling and analysis phase will allow a rigorous quantitative human and ecological risk assessment to be performed. This report constitutes the first of a series of steps as outlined in the IAG schedule toward quantifying the risk and initiating any needed remedial actions.

EXECUTIVE SUMMARY

This Remedy Report for Solid Waste Management Unit (SWMU) 199 was prepared in response to requirements in the draft Interagency Agreement (IAG). The IAG identifies the following primary objectives for the Remedy Report:

1. Detail the history of the SWMU 199 remedy ordered by the U.S. District Court;
2. Detail the activities conducted to date to implement the remedy;
3. Detail the effectiveness of the remedy; and
4. Provide a health assessment which identifies the public health risk associated with potential exposure of the public prior to completing any site remediation, during implementation of the remedy, and after completion of the remedy.

After evaluating the existing data for SWMU 199, it became apparent that the health assessment would have to be a qualitative assessment. The quantity and quality of existing information is insufficient to perform a rigorous quantitative human health risk assessment. As a result, this Remedy Report includes a Qualitative Human Health Risk Assessment (Section 4.0) which evaluates release mechanisms, transport mechanisms, and exposure routes associated with SWMU 199.

While a quantitative risk assessment is needed to fully evaluate potential exposures to the public, the qualitative assessment in this report provides valuable information which will allow future data collection activities (e.g. Remedial Investigations) to focus on the most significant exposure pathway. The following discussions provide a brief summary of the information provided in this report in support of the objectives listed above.

SWMU 199 is one of four SWMUs in Rocky Flats Plant (RFP) Operable Unit No. 3 (OU 3). SWMU 199 consists of approximately 350 acres (142 hectares) of land which were the subject of a 1975 lawsuit filed by landowners against the U.S. Department of Energy (DOE) and its contractors at the RFP. A Settlement Agreement was finalized in July 1985, and required the RFP to undertake remedial actions (remedy) on those portions of the land containing plutonium at concentrations exceeding Colorado Department of Health (CDH) guidelines. The areas which are required to be remediated comprise SWMU 199.

The available historical information for SWMU 199 indicates that the great majority of the soil plutonium contamination at SWMU 199 originated as windborne particulates from the 903 Pad. This source of the contamination was effectively eliminated in November 1969, when the 903 Pad was capped with asphalt. In general, the soil contamination is limited to the upper few inches of soil. The remedy involves tilling the contaminated areas to reduce plutonium concentrations, and revegetating these areas to control wind and water erosion of the soil. To date, approximately 110 acres (45 hectares) have been tilled and revegetated. While plutonium concentrations in these areas have been reduced by tilling to below the CDH guidelines, the success of the revegetation to date has been limited by the following factors:

- insufficient amounts and/or poor seasonal distribution of precipitation
- extremely rocky surfaces or clayey soils
- intense competition from weeds, which provide insufficient soil stabilization
- an expanding prairie dog population
- the effects of slope and aspect on soil water

Specific actions to increase revegetation success have been identified (Section 2.2.3.3), and include actions to change the seed mixture, introduce irrigation, and control prairie dog and weed populations.

The results of the qualitative risk assessment (Section 4.0) indicate that plutonium is the only contaminant of significant concern, and that airborne dust is the only credible environmental pathway that could impact the public. Existing data indicate that there has not been any measurable exposure to human receptors downwind of SWMU 199 prior to, during, or after the remedy actions taken to date. Without performing a quantitative risk assessment, it is not possible to differentiate between the potential risk to human health prior to remedy implementation, during implementation, or after implementation. It is also uncertain without a quantitative assessment whether the remedy implementation activities will in fact reduce the potential risk.

The information presented in this report points to the following conclusions about SWMU 199:

- The concentration of plutonium in the soil at SWMU 199 appears to be very low. The data that support this conclusion, derived from a number of site studies, have not been validated and may not be of comparable quality, and are therefore not considered conclusive.

- The airborne dust pathway from SWMU 199 is the most significant in terms of human health risk.

- The completed exposure pathways are the same for pre-remedy, remedy implementation, and post-remedy conditions at SWMU 199. If the remedy is successfully implemented, however, the concentration of plutonium available for transport as airborne dust will be reduced through tilling, and the probability of occurrence for the airborne dust pathway will be reduced through revegetation.

- The control measures being used to reduce off-site impacts during remedy implementation at SWMU 199 have been effective. No measurable airborne impacts to human receptors downwind of SWMU 199 have been observed since control measures have been implemented.

It is recommended that additional data necessary to support a quantitative risk assessment for SWMU 199 be collected. Additional data needs are identified in Section 4.14. The data collection should be integrated into future Remedial Investigation activities.

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LIST OF ACRONYMS AND ABBREVIATIONS

µm	Micrometer (10^{-6} meters)
ANL	Argonne National Laboratory
ARARs	Applicable or Relevant and Appropriate Requirements
Bq	Becquerels
CDH	Colorado Department of Health
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWA	Colorado Hazardous Waste Act
Ci	Curies
cm	Centimeter (10^{-2} meters)
CSU	Colorado State University
DNA	Deoxyribonucleic acid
DOE	U.S. Department of Energy
dpm	Disintegrations per minute
DWR	Colorado Division of Water Resources
EPA	U.S. Environmental Protection Agency
ft	Feet
g	Gram
gal	Gallons
GI	Gastro intestinal
He	Helium
hr	Hour
IAG	Interagency Agreement
ICRP	International Commission on Radiation Protection
in	Inches
Kd	Distribution coefficient (ratio of concentration in soils to concentration in water for plutonium)
km	Kilometers (10^3 meters)
kow	Logarithmic octanol-water partition coefficient
l	Liter

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

lbs	Pounds
m	Meter
m^{-1}	Per meter
mm	Millimeter (10^{-3} meter)
mph	Miles per hour
NCP	National Oil and Hazardous Substances Contingency Plan
NEPA	National Environmental Policy Act
NPDES	National Pollution Discharge Elimination System
NRC	National Research Council
OU	Operable Unit
pCi	Picocuries (10^{-12} Curies)
PuO_2	Plutonium dioxide
QA	Quality Assurance
QC	Quality Control
RAG	Risk Assessment Guide
RCRA	Resource Conservation and Recovery Act
RFP	Rocky Flats Plant
SCS	Soil Conservation Service, U.S. Department of Agriculture
sec	Second
SWMU	Solid Waste Management Unit
TGLD	Task Group on Lung Dynamics
U.S.	United States
USGS	United States Geological Survey, U.S. Department of the Interior
VOCs	Volatile Organic Compound

LIST OF DEFINITIONS

Completed Exposure Pathway: The route a chemical or radionuclide takes from a source to an exposed organism. A completed exposure pathway describes a unique mechanism by which an individual or population is exposed to a chemical or radionuclide originating from the site. Each completed exposure pathway includes a source, a transport media, a mode of uptake, and a receptor.

Detection Limit: The lowest value that can be reliably detected above the background noise of a given anlaytical instrument or method.

Health Assessment: The assessment of chemical or radiological releases from a site and the analysis of public health threats resulting from those releases.

Qualitative Risk Assessment: An estimate of the likelikhood of an adverse health effect by analyzing both exposure and dose response data in a non-numerical manner.

Quantitative Risk Assessment: Based on completed exposure pathways, probabilities that an individual will develop cancer over a lifetime of exposure are estimated from projected intakes and chemical/radionuclide-specific dose response information.

Risk: A unitless probability of an individual being affected by an event.

Risk Coefficient: For the purposes of this document, a unitless probability of an individual developing cancer from a chronic daily intake of plutonium averaged over seventy years.

1.0 INTRODUCTION

This Remedy Report presents a summary of the available historical information, an evaluation of the effectiveness of the remedy actions implemented to date, and a qualitative human health risk assessment for SWMU 199 of RFP OU 3 (Off-Site Releases), located immediately outside of the RFP eastern boundary. OU 3 is unique among Rocky Flats operable units in that it is located outside the RFP boundaries. The RFP is owned by the DOE and contractor-operated by EG&G Rocky Flats, Inc. (EG&G) as a nuclear weapons research, development and production complex. The RFP is situated on 6,550 acres (2,653 hectares) of federal property 16 miles (25.7 kilometers) northwest of downtown Denver, Colorado (Figure 1-1).

SWMU 199 is comprised of approximately 350 acres (142 hectares) of land which were the subject of a 1975 lawsuit filed in U.S. District Court (Civil Action No. 75-M-1162) by the land owners against the DOE and its contractors at Rocky Flats (hereafter referred to as the lawsuit), alleging contamination of the land surface by releases from the RFP during its operating history. Several technical investigations and studies of the site were conducted by the various parties to the lawsuit to provide supporting evidence in the case. A Settlement Agreement finalized in July 1985 (the Settlement Agreement) required that the RFP undertake remedial action on those portions of the land containing plutonium at concentrations exceeding CDH guidelines. Portions of two contiguous tracts of land, which are currently owned by the City of Broomfield and Jefferson County, were targeted for remediation based upon the CDH guideline.

OU 3 also includes three nearby reservoirs, designated SWMUs 200, 201 and 202, which are the subject of a separate report. A fifth off-site unit within OU 3, SWMU 198 (VOCs in Groundwater), does not require any action as a whole. Contamination associated with SWMU 198 will be addressed by other individual RFP site investigations.

1.1 PURPOSE AND OBJECTIVES

The purpose and objectives of this report are derived primarily from the draft IAG between the CDH, the U.S. Environmental Protection Agency (EPA), and the DOE (EPA, 1989a). The IAG identifies the following primary objectives for the Remedy Report:

1. Detail the history of the SWMU 199 remedy ordered by the U.S. District Court;

2. Detail the activities conducted to date to implement the remedy;

3. Detail the effectiveness of the remedy; and

4. Provide a health assessment which identifies the public health risk associated with plausible potential exposure of the public prior to completing any site remediation, during implementation of the remedy, and after completion of the remedy.

The specific objectives for this report are listed below and are based upon the four primary objectives of the draft IAG:

- Describe SWMU 199 site physical characteristics
- Provide a historical summary of litigation, environmental investigations and remedial activities at SWMU 199
- Evaluate the efficacy of remedial action conducted to date in accomplishing the intended goals
- Formulate a conceptual model for contaminant fate and transport from SWMU 199
- Provide a preliminary qualitative health risk assessment for the site which considers three scenarios:
  - No action
  - Implementation of the remedy
  - Post remedy
- Identify additional data needed to support a quantitative risk assessment for SWMU 199.

1.2 REGULATORY BACKGROUND

The current iteration of the IAG groups the SWMUs at the RFP into 16 Operable Units (OUs), one of which is OU 3. OU 3 formerly was designated Operable Unit No. 10. The present RFP OU system has emerged from IAG renegotiation, which has increased the number of OUs from ten to sixteen and changed their relative order of priority.

The primary source for the scope of work for investigation and remediation of RFP OUs is the IAG, which specifies a phased approach tailored to the particular requirements of the RFP. All response activities performed by the DOE under the IAG are to be consistent with the applicable requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), the Resource Conservation and Recovery Act (RCRA), the Colorado Hazardous Waste Act (CHWA), pertinent EPA guidance documents, and the National Environmental Policy Act (NEPA).

Under the terms of the 1985 Settlement Agreement with landowners, a 250 acre (101 hectare) tract of land was transferred to Jefferson County for use in its open space program, and 100 adjoining acres (41 hectares) were allotted to the City of Broomfield for future expansion of Great Western Reservoir. These lands were deeded with the understanding that the RFP would implement remedial activities on these 350 acres (142 hectares) as specified in the Settlement Agreement, at the request of the owners. Although measured plutonium concentrations on the lawsuit subject acreage were less than the EPA screening level of approximately 20 picocuries per gram (pCi/g) (0.74 becquerels per gram (Bq/g)), the remedial action level for the remedy was based upon a more stringent 0.9 pCi/g (0.03 Bq/g) adopted by the CDH as a special construction guideline. Jefferson County requested in 1986 that remediation commence on the portions of their acreage targeted for remediation. To date, Broomfield has not requested that the RFP begin remediation on their affected acreage.

1.3 <u>REPORT ORGANIZATION</u>

The remainder of this report is organized into the following sections:

- Section 2.0 provides a discussion of site characteristics, site history, a description of the remedial actions performed to date, and a discussion on the effectiveness of the remedy.
- Section 3.0 provides a description of the site conceptual model used in the qualitative human health risk assessment.
- Section 4.0 provides the qualitative human health risk assessment, including identification of data needed to conduct a quantitative human health risk assessment.
- Section 5.0 provides conclusions and recommendations.
- Section 6.0 provides references.

2.0 SITE BACKGROUND AND DESCRIPTION

The RFP fabricates metal components for nuclear weapons from plutonium, uranium, beryllium and stainless steel. Additional production activities include chemical recovery and purification of recyclable transuranic radionuclides, metal fabrication and assembly, and related control functions. Support activities include research and development in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry and physics. These operations generate nonhazardous, hazardous, radioactive and mixed radioactive waste streams (DOE, 1987). The 400 acre (162 hectare) main production area of the RFP is surrounded by a 6,150 acre (2,491 hectare) buffer zone which delineates the RFP boundary (Figure 1-1).

2.1 LOCATION AND PHYSICAL DESCRIPTION

SWMU 199 is located on two tracts of land totalling 350 acres (142 hectares) in the southern half of Section 7 and the western half of Section 18, Township 2 South, Range 69 West. Both areas are just outside the eastern boundary of the RFP, approximately 1.5 miles (2.4 kilometers) east of the main production area of the plant (Figure 2-1). Both are generally downwind and downgradient of the RFP. Public access to the SWMU 199 area is restricted.

2.1.1 Historical Contamination from the RFP

Shallow soil sampling conducted in association with the lawsuit indicated that parts of the 350 acres (142 hectares) contained soils with concentrations of plutonium in excess of CDH guidelines, thereby targeting the lands for remedial action under the Settlement Agreement. Numerous studies have been conducted which address plutonium concentrations in the soil at and around the RFP. These studies have sought to identify plutonium sources, define plutonium transport and mobility in area soils, and to characterize the distribution of plutonium in the soil. The results of these studies are addressed in detail in Sections 2.0 and 3.0 and are referenced in Section 6.0. Among the more significant findings and interpretations from these studies relevant to SWMU 199 are:

- The only compounds with soil concentrations within SWMU 199 above background concentrations (as a result of releases from the RFP) are plutonium and americium. Americium is a decay product of plutonium (Rockwell, 1985a).

- The great majority of the plutonium and americium at SWMU 199 originated as windborne particulates from the 903 Pad, an area with plutonium and americium soil contamination in the southeastern part of the RFP main production area (Krey and Hardy, 1970). It is believed that the plutonium contamination mainly resulted from the 903 Pad area where 55-gallon drums of oil contaminated with plutonium corroded and leaked onto the ground over a 10-year period starting in 1958. Winds carried the contaminants downwind and offsite until an asphalt cover over the 903 Pad was completed in November 1969, effectively eliminating the source. The total amount of plutonium carried offsite from the 903 Pad area and other RFP source areas is estimated to be 5.8 curies (Ci) (2.1×10^{11} Bq) (Krey and Hardy, 1970). No known further contamination of SWMU 199 as a result of RFP operations has occurred since this time (Rockwell, 1988a).

- As of 1970, the top 8.3 inches (in) (21 centimeters (cm)) of plutonium-contaminated soils around the RFP contained 99% of the total ecosystem plutonium inventory; one-half of the total plutonium was in the top 1.2 in (3.0 cm) (Krey and Hardy, 1970).

- Near the 903 Pad source area, wind resuspension of settled dust containing plutonium from grass blades, rather than from soil, appears to be the dominant historical pathway (Rockwell, 1989). The most likely pathways of plutonium migration from the SWMU 199 area are through wind and water erosion of surface soil (SCS, 1985).

2.1.2 Site Conditions

The following sections address the soils, hydrology, climatology and biota of SWMU 199 as each pertains to contaminant fate and transport and to remedial activities at the site.

2.1.2.1 Soils

SWMU 199 soil characteristics were considered by the U.S. Department of Agriculture Soil Conservation Service (SCS) in providing erosion control and revegetation recommendations for the remedy implementation (SCS, 1985). The SCS recommendations were based in part upon soil data derived from the SCS Soil Survey of the Golden Area, Colorado (SCS, 1980). According to this survey, soil at the SWMU 199 site was mapped as a soil complex, meaning the soil types are so intermingled that it is not feasible to differentiate them. For practical purposes, SWMU 199 soils may be characterized as Denver-Kutch-Midway clay loams with 9 to 25 percent slopes. The following information is taken from SCS descriptions of this soil type. More detailed information concerning soil chemistry and its relevance to contaminant fate and transport is presented in Section 3.0.

The soil complex as originally mapped by the SCS at the SWMU 199 site averages 35% Denver soil, 30% Kutch soil and 20% Midway soil, with Denver and Kutch soils on hillslopes and Midway soil on ridge crests (SCS, 1980). It is assumed that the remaining 15% is comprised of other soil types. Site-specific estimates given by the SCS for their remedy recommendation for SWMU 199 are 50% Denver, 30% Kutch and 20% Midway (SCS, 1985).

The Denver soil is deep and well drained. It formed from calcareous, clayey material derived predominantly from mudstone and shale. Typically the surface layer is a mildly alkaline clay loam about 6 in (15 cm) thick. The upper subsoil is a mildly to moderately alkaline clay averaging 14 in (36 cm) thick, underlain by a moderately alkaline clay some 10 in (25 cm) thick. The lower subsoil, to a depth of 60 in (152 cm), is also moderately alkaline clay. Permeability is relatively low, ranging from 0.2 to 0.6 inches per hour (in/hr) (0.5 to 1.5 centimeters per hour (cm/hr)) in the surface layer and 0.06 to 0.6 in/hr (0.15 to 1.5 cm/hr) in the subsoil. Fractures in the soil due to shrinking and swelling may increase permeability. Available water capacity is high. Effective rooting depth can exceed 60 in (152 cm). Wind erosion potential is moderate. Because runoff is heavy, the water erosion potential is high. The shrink-swell potential is also high due to high clay content. Rock fragments typically comprise 0 - 15% of the total volume (SCS, 1980).

The Kutch soil is moderately deep and well drained. Like the Denver soil, the Kutch formed from calcareous, clayey material derived primarily from mudstone and shale. The surface layer is a neutral clay loam 3 in (8 cm) thick. The upper 8 in (20 cm) of the subsoil is neutral to mildly alkaline clay, while the lower 16 in (40 cm) are moderately alkaline clay. It typically overlies soft, interbedded shale bedrock at a depth of 25 in (64 cm). Permeability is low, ranging from 0.2 to 0.6 in/hr (0.5 to 1.5 cm/hr) in the surface layer and 0.06 - 0.2 in/hr (0.15 - 0.5 cm/hr) in the subsoil. Fractures in the soil due to shrinking and swelling may increase permeability. Available water capacity in the Kutch soil is low. The effective rooting depth is 20 to 40 in (50 to 100 cm). Heavy runoff creates a high potential for water erosion. Wind erosion potential is slight, and the shrink-swell potential is high. Rock fragments typically comprise 0 - 15% of the total volume (SCS, 1980).

The Midway soil is shallow and well drained, and formed from the same materials as the Kutch and Denver soils. The typical surface layer is a neutral clay loam 3 in (8 cm) thick. This is underlain by a mildly alkaline clay loam about 8 in (20 cm) thick. Moderately alkaline clay extends beneath this to a depth of 14 in (36 cm). Soft shale typically exists below this depth. Permeability ranges from 0.2 to 0.6 in/hr (0.5 to 1.5 cm/hr) in the surface layer and 0.06 to 0.2 in/hr (0.15 to 0.5 cm/hr) in the subsoil. Fractures in the soil due to shrinking and swelling may increase permeability. Available water capacity is low. The soil has an effective rooting depth of 6 to 20 in (15 to 50 cm). Heavy runoff creates a high risk of water erosion, and wind erosion potential is moderate. As with the Denver and Kutch soils, the shrink-swell potential is high. Rock fragments typically comprise 0 - 15% of the total volume (SCS, 1980).

Establishment and maintenance of grasses and other vegetation in the Denver-Kutch-Midway soil complex are restricted by the slope, the clay loam surface layer and clayey subsoil, and, on the Midway soil, shallow depth to bedrock. The complex is described as generally unsuitable for cultivation due to the high risk of erosion. When attempting to vegetate the soil, supplemental irrigation at planting time and during dry periods is recommended (SCS, 1980).

The SCS estimated annual soil loss due to erosion for northeast-facing slopes at the SWMU 199 site under worst case conditions (i.e. bare soil) and under remedial activity conditions (i.e. tilled, with a cover crop). Total annual loss through water and wind erosion may range from 93 - 143 tons per acre (209-321 metric tons per hectare) under worst-case conditions. This loss would be reduced to 13 - 22 tons per acre (29-49 metric tons per hectare) under remediation without using protective mulch between plowing and establishment of a cover crop. If such a mulch was used, the loss due to erosion is predicted to be 1 - 3 tons per acre per year (2.2-6.7 metric tons per hectare per year), due almost exclusively to water erosion. Gullying, which might increase the total loss in the worst-case scenario, was identified as a likely problem if the land was not adequately protected during remedial activities (SCS, 1985).

Revegetation of portions of SWMU 199 has been hampered by abundant cobbles in the soil, which were brought to the surface by tilling. Surface accumulations of cobbles are estimated to cover some 30% of the total tilled acreage, and in some areas cover nearly 90% of the surface

(EG&G, 1990a). An inactive gravel pit is located in the northeastern corner of the Section 7 remedial acreage. It can be inferred from these observations that the rock fragment content of portions of the SWMU 199 soil is appreciable, perhaps 15 - 20% or more by volume.

2.1.2.2 Surface Water

Surface water features at and near the SWMU 199 site include drainages and impoundments (Figure 2-1). The City of Broomfield acreage in Section 7 abuts Great Western Reservoir to the north. The Jefferson County open space land in Section 18 surrounds Mower Reservoir. Mower Reservoir is fed by a diversion from Woman Creek, which flows from the southern part of the RFP. Outflow from Mower Reservoir discharges east off of the SWMU 199 site, eventually entering Church Ditch. Walnut Creek itself traverses the southern end of SWMU 199 before discharging into Standley Lake approximately one mile southeast of the site.

Existing slopes on the site are 2 - 15%, generally to the east. Slopes to the west also are present (SCS, 1985). Topographic maps of the site indicate that most of the acreage drains into two ephemeral channels which flow southeast from the area into Standley Lake (USGS, 1980). Portions of the northernmost City of Broomfield acreage in Section 7 drain north into Great Western Reservoir. The southernmost Section 18 acreage drains directly into Woman Creek.

The frequency and amount of surface runoff depends upon the infiltration capacity of the soil, surface vegetation, and slope. The clay loam soil at the site is assumed to have a relatively low infiltration capacity due to its clay content, except where fractures may have significantly increased the vertical permeability. Vegetation cover, addressed in more detail in Section 2.1.2.5, is somewhat sparse at the site, consisting mostly of native grasses and weeds in unremediated areas, and weeds in remediated areas. Some surfaces are poorly vegetated due to prairie dog infestation and cobbles brought to the surface by tilling (EG&G, 1990a). Application of mulch on the surface (see Section 2.2.3.2) would reduce the likelihood of surface runoff.

Although these factors suggest that surface runoff from precipitation events, snowmelt and other incident water (e.g. irrigation) may occur readily on the site, a site-wide study of the hydrology of the RFP determined that runoff in the Woman Creek basin averages only 1.4% of rainfall, indicating either a high infiltration rate for the soil or a high surface retention capacity. This figure was based on records for long-duration, low-intensity storms; runoff may be much higher for a short-duration, high-intensity event (USGS, 1976).

2.1.2.3 Ground Water

Although little site-specific information is available for ground water at SWMU 199, plant-wide hydrogeologic studies provide an indication of ground water conditions in the vicinity of the RFP. Two hydraulically-connected ground water systems occur at the RFP: A shallow, unconfined system which is present in saturated surficial deposits in many areas of the RFP, and a confined system in sandstones and claystones of the underlying Arapahoe Formation which, is assumed to also underlie SWMU 199 surficial deposits.

The unconfined system is recharged by infiltration from incident precipitation and from surface water (e.g. drainages and reservoirs). Ground water flow is generally to the east and towards drainages. Ground water locally discharges as seeps or springs in drainages, especially where the surficial deposit/bedrock contact is exposed. Large water table fluctuations may occur in the shallow system in response to seasonal variations in recharge and discharge, with the highest water levels generally occurring during the months of May and June and the lowest water levels generally occurring in January and February. As a result of these fluctuations the lateral and vertical extent of saturated surficial deposits varies seasonally. The Rocky Flats Alluvium is the predominant surficial deposit in the main production area of the RFP. The USGS calculated horizontal flow velocities in the Rocky Flats Alluvium at 7-18 feet per day (ft/day) (2.1-5.5 meters per day (m/day)). Horizontal flow velocity in valley fill deposits below the Rocky Flats Alluvium terrace was calculated at 15-25 ft/day (4.6-7.6 m/day) (USGS, 1976). A more recent study, using much lower hydraulic conductivity estimates for both deposits, calculated average horizontal flow at 0.6 ft/day (0.18 m/day) in the Rocky Flats Alluvium and 0.09 ft/day (0.03 m/day) in the valley fill (Hydro-Search, 1985).

Ground water conditions in the Arapahoe Formation are controlled primarily by lenticular sandstone bodies within the claystone. Recharge to the sandstones occurs primarily from the overlying shallow ground water system, either through direct contact (sandstone subcrops) or by leakage through the claystone. Infiltration from streams may also recharge the system, especially in drainages north and south of the RFP. Ground water flows east towards a regional discharge area along the South Platte River, some 20 miles (32 kilometers) east of the plant. Local seeps occur along the sides of drainages where the Arapahoe Formation crops out. Calculated horizontal flow velocities for the system average 0.1 ft/day (0.03 m/day) in the sandstones and approximately 9 x 10^{-4} ft/day (2.7 x 10^{-4} m/day) in the claystone. A relatively steep downward gradient is also observed in areas of the formation. The effects on ground water movement by faulting in the Arapahoe Formation are not known. The Eggleston Fault, a high-angle normal fault, has been inferred to extend from the north between the main production area and the eastern boundary of the RFP, and possibly impacts ground water flow from the RFP towards SWMU 199 (USGS, 1976; Hydro-Search, 1985).

Currently, there are no dedicated ground water monitoring wells outside of the RFP eastern boundary. Numerous privately-owned water wells, however, have been drilled just east of the RFP. Limited information was obtained from drilling and filing records held by the Colorado Division of Water Resources. These records suggest that the thickness of surficial deposits ranges from 15 to 50 feet (4.6 to 15 meters) and averages approximately 25 feet (7.6 meters) near SWMU 199. Surficial deposits are typically described as clay, sandy clay or clay with gravel and boulders, locally capped by five or six feet of topsoil. The underlying bedrock (assumed to be the Arapahoe Formation) is described as alternating layers of shale and sandstone. Most of the wells studied were completed in Arapahoe Formation Sandstones at depths ranging from 35 - 275 feet (10.7 - 84 meters). Static water levels averaged 10 - 50 feet (3.0 - 15 meters) higher than the screened interval, indicating moderate pressure head in the formation. The static water level was 20 feet (6.1 meters) in one well completed in the shallow aquifer in the southwest corner of Section 6, just north of the SWMU 199 area (DWR, 1990).

2.1.2.4 Climatology

Water and wind erosion are the primary contaminant transport mechanisms for contaminated soils at SWMU 199. These mechanisms are discussed in greater detail in Sections 3.0 and 4.0.

Water erosion of soil occurs as a result of surface runoff. Surface runoff at SWMU 199 is the result of precipitation, primarily from rainfall and to a lesser extent from snowmelt. The volume of runoff is controlled by the intensity and duration of precipitation, antecedent soil moisture, and the surface and soil characteristics discussed in Section 2.1.2.2. Rainfall intensity and duration vary widely. During a three-year hydrological study of the RFP between 1972 - 1975, rainfall intensities varied from <0.1 in/hr (<0.25 cm/hr) to approximately 0.5 in/hr (1.25 cm/hr) (USGS, 1976). Frontal storms with long, low-intensity rainfall durations occur in the fall and early spring, while short, intense cloudbursts are frequent in the late spring and summer months. The cloudbursts produce much greater surface runoff than the frontal storms, despite their typically short durations. Spring snowmelt can also generate high runoff. Average rainfall for the RFP area is approximately 15 inches per year (in/yr) (38 cm/yr), with 40 percent of this falling during the spring. Snowfall averages 85 in/yr (216 cm/yr) (DOE, 1980).

Winds in the area are variable in direction but are predominantly from the west (westerly). Stronger winds occur during the winter months (DOE, 1980). Wind data for 1989, which meets EG&G Rocky Flats Environmental Restoration Program quality assurance standards, are discussed in Section 4.0.

2.1.2.5 Biota

Biota at the SWMU 199 site is addressed only as it pertains to contaminant fate and transport and to remedial activities at SWMU 199.

The vegetation in the SWMU 199 area consists of native grasses and weeds with various shrubs and small trees along the Woman Creek drainage. Native grasses common to the area include western wheatgrass, green needlegrass, blue grama, and sideoats grama (SCS, 1980). Portions of the acreage formerly were cultivated with winter wheat.

Lands which have been tilled and seeded as part of remediation currently are dominated by weeds, including Canadian, Russian and musk thistles, mustards, bindweed and cheatgrass (EG&G, 1990a). These weeds provide fair but unreliable stabilization of soils. Planted grasses have become established on approximately 10% of the northern (Section 7) remedial acreage and provide excellent soil stabilization. The seed mix used included western wheatgrass, sideoats grama, pubescent wheatgrass, and smooth brome (SCS, 1985). Winter wheat and sorghum have also been planted on these lands as winter cover to help prevent soil erosion.

Prairie dogs have been identified as a potential threat to revegetation of the remedial acreage. As of late 1989, the prairie dog population impacted approximately 60% of the northern (Section 7) land and 30% of the southern (Section 18) land. Prairie dogs contribute to soil destabilization through burrowing, consumption of new seedlings, and stripping of vegetation around burrows for visual defense against predators. While burrowing may locally dilute plutonium concentrations, it may also provide a pathway for deeper infiltration of plutonium into the soil and subsoil at SWMU 199. Proposed remedial actions for 1990 include suppression of the prairie dog population through physical and/or toxicogenic means (EG&G, 1990a).

2.2 HISTORY OF SITE

The following sections address past and present land usage at SWMU 199, summarize the legal history of the site, and describe the remedial actions undertaken to date at the site as a result of the Settlement Agreement.

2.2.1 Ownership and Usage

The SWMU 199 acreage originally was privately owned by the lawsuit plaintiffs and utilized as pasture for grazing livestock. Portions of the land were cultivated with winter wheat; these areas had been tilled for 25 years or more prior to their abandonment in 1980 (Rockwell, 1987). An inactive gravel pit also is located in the northwest corner of the Broomfield acreage. The operational history of this pit is not known.

As a condition of the Settlement Agreement, land totalling 350 acres (142 hectares) was transferred from the plaintiffs to the City of Broomfield and Jefferson County. The 100 acres (40 hectares) in Section 7 deeded to Broomfield were to be used for expanding Great Western Reservoir. To date this reservoir expansion has not occurred. The land has remained in its original state and public access is restricted. The 250 acres (101 hectares) of Jefferson County land in Sections 7 and 18 were dedicated to that county's Open Space program.

2.2.2 History of Litigation

In May 1975, a lawsuit was filed against Rockwell International Corporation, Dow Chemical Company, and the United States of America by the Church (McKay) plaintiffs and Great Western Venture partnership (U.S. District Court, 1985a). The plaintiffs' holdings consisted of approximately 2,000 acres (810 hectares) to the west, south and east of the RFP. The plaintiffs alleged that their lands were damaged by releases of plutonium and other radioactive materials from the RFP. The plaintiffs claimed that these materials had rendered their land unfit for human habitation and had diminished the market value of their properties for commercial, residential or other non-agricultural uses. The plaintiffs further claimed that the mere presence of the RFP next to their property further diminished the value of their properties. The defendants acknowledged that releases of radioactive materials occurred at various times from the 1950s through the late 1960s, but contended that the releases had not violated applicable regulations established for the protection of the public (U.S. District Court, 1985a).

On the basis of scientific exhibits presented early in the proceedings and objections raised during the hearings, the parties agreed to conduct a field investigation on the plaintiffs' lands that would include collection and analysis of soil samples for plutonium and americium. Prior to commencement of the field investigation, the parties agreed to specific methodologies for collecting, preparing, and analyzing the soil samples (Rockwell, 1977). The field investigation program commenced in 1977 and continued through 1979. Results of the program indicated radionuclide levels on the plaintiffs' properties ranging from <0.01 to 3.4 pCi/g (3.7×10^{-4} to 0.13 Bq/g). After additional testing, the parties agreed to accept some of the data as evidence for the trial (U.S. District Court, 1985a).

In March 1978 the Ackard-Butler interests intervened in the legal proceeding and were added to the lawsuit as plaintiffs. Church and Ackard-Butler added, by amended complaint, the State of Colorado and Jefferson County, Colorado as defendants in 1982, claiming that if the government defendants prevailed in this litigation, then the State and County had acted unlawfully in precluding development of plaintiffs' lands. In 1982 the Court dismissed the plaintiffs' claims for lack of jurisdiction, ruling that the issues were not determinable under Rule 56. In 1983, the

Tenth Circuit Court of Appeals reversed this ruling, stating that the plaintiffs were entitled to a trial or trials on some of their claims.

In December 1984 a settlement was reached between the defendants and plaintiffs (U.S. District Court, 1985b). The Settlement Agreement, as amended on July 2, 1985, called for ripping, plowing and discing (referred to generically in this report as "tilling") of affected soils to reduce plutonium concentrations to less than the CDH guideline of 2 disintegrations per minute per gram (dpm/g), which is approximately 0.9 pCi/g (0.03 Bq/g). Historical incidents (e.g., Palomares, Spain, circa 1960) established a precedent for tilling plutonium contaminated lands, which reduces the concentration of plutonium by dispersing it throughout the soil (Lawton, 1990). Results of soil sampling during 1977 indicated that plutonium levels in several tilled wheat fields on the plaintiffs' property were consistently lower than levels on adjacent undisturbed ground. The agreement required the RFP to conduct additional soil sampling to verify that plutonium concentrations were reduced, and to revegetate the tilled soils to provide stabilizing vegetation. The option of remediating the land through "other processes" was left open in the agreement. The selected remedial actions were jointly agreed upon by Rockwell International, DOE, and CDH. One of the conditions of the agreement was the preparation and dissemination by the RFP of an annual status report on remediation progress. The Settlement Agreement also made provisions in the event there are any future release(s) from the RFP. If a release occurs, the RFP must demonstrate that contaminants on affected properties do not exceed applicable standards.

Court-supervised soil sampling was conducted in 1985 on the affected lands according to CDH sample collection protocol. Approximately 350 acres (142 hectares) of land with concentrations of plutonium greater than 0.9 Pci/g (0.03 Bq/g) were delineated by the sampling program. These areas, which were subsequently transferred to Jefferson County and the City of Broomfield, are the only land to which the Court-ordered remedial action applies. Another 490 acres (198 hectares) pertinent to the settlement did not exceed the soil plutonium concentration limit and therefore were not targeted for remedial action.

The 1985 sampling data corroborated earlier observations that areas originally cultivated with wheat contained substantially lower concentrations of near-surface plutonium. It was also noted that average plutonium concentrations in the surficial soil appeared to have decreased significantly between 1977 and 1985. This apparent decrease may have been due to plutonium migration (see discussion in Section 3.0). The lower values may also have resulted from: (1) the use of different laboratories utilizing differing analytical techniques; or (2) the significantly larger area represented by the 1985 samples (10 acres (4 hectares) per sample) as compared to the 1977 samples (0.2 acres (0.08 hectares) per sample) (Rockwell, 1987).

On May 28, 1986, Jefferson County requested that the remedial actions be undertaken on their lands (Rockwell, 1988b). To date, the City of Broomfield has not requested that their lands be remediated.

2.2.3 Remediation of Jefferson County Lands

Soil remediation currently is underway on approximately 250 acres (101 hectares) of Jefferson County lands. The following sections address the scope of the remedial activities and the history and present status of the remediation.

2.2.3.1 Scope of Soil Remediation

The July 1985 amended Settlement Agreement outlines a specific course of remedial action for plutonium contaminated lands. The nature and scope of remedial actions were developed and agreed upon by Rockwell International, DOE, and CDH. Recommendations concerning erosion control and revegetation were provided by the SCS on behalf of Rockwell. It should be noted that the SCS concluded that it would be best to leave the affected lands undisturbed rather than to attempt remediation (SCS, 1985).

The Settlement Agreement specifies the following remedial actions (U.S. District Court, 1985b):

- Spring ground preparation (plowing and discing ("tilling") to reduce plutonium concentrations through mixing and dilution) plus a summer (June) cover crop
- Drilling grass seed into cover crop stubble in the fall
- Supplemental mulch

- Timely irrigation during the establishment period
- Weed control to ensure successful establishment of grasses.

More specifically, the Settlement Agreement requires that the remediation shall consist of the following remedial actions, any of which may be modified by agreement between the owner of the land and the RFP:

- Erosion Control -- Small areas of land may be worked on all at once, but larger areas will require a phased approach. Land shall be broken out in alternating strips perpendicular to the prevailing winds or, on long slopes, on the contour. Strip widths shall be determined by a number of site-specific variables, including soil characteristics, slope length and gradient, vegetative cover, and field width. Work on the other set of strips shall not begin until the first set is successfully reestablished in grass. Properly done, this will minimize erosion in "normal" weather. There shall be some standby provisions for emergency erosion control such as extra mulching and sediment-trapping diversions, in the event of unusual weather.

- Soil Preparation -- May is the logical time for the plowing, discing, chiseling, and harrowing operations necessary to satisfy the soil mixing objective of the remedial action plan and to prepare a decent seedbed for the cover crop. The total amount of tillage required depends on how well the mixing satisfies the plutonium concentration standard. Additions of nitrogen and phosphorous shall be made as necessary.

- Cover Crop -- The revegetation scheme utilizes a cover crop (forage sorghum) which will be planted in June when the soil has warmed to 60°F (16°C). Supplemental irrigation may be required.

- Grass Seeding -- Grass shall be drilled into the ground after November 1.

- Mulch -- The cover crop should leave adequate residue for soil protection. If it is insufficient in some areas, mulch will be needed.

- Supplemental Irrigation -- Timely irrigation through the establishment period shall be used to improve the chances for a successful planting.

- Special Conditions -- In order to prevent possible resuspension of plutonium on the soil surface, the mixing operation will be conducted only when the soil moisture content is greater than 15% and the wind velocity is less than 15 mph (24 km per hour). Portable air samplers will be operated downwind from the soil mixing operations during all phases of the program. The samples will be analyzed for plutonium and all activities will be shut down if the plutonium concentration in the air exceeds a control level of 0.02 pCi/cubic meter (7.4 x 10^{-4} Bq per cubic meter).

- Maintenance -- Areas that do not develop satisfactory ground cover in a reasonable length of time (two growing seasons) would be reseeded after an evaluation of the circumstances by representatives of Rockwell (now EG&G) and the land owners involved.

2.2.3.2 Effectiveness of the Remedy Implementation

Remedial activities began in June 1986 on approximately 100 acres (41 hectares) Jefferson County land in Section 7, south of Great Western Reservoir. The soil remediation followed guidelines set forth in exhibit 8 of the amended Settlement Agreement (EG&G, 1990b). The following account of 1986 remedial activities in Section 7 is summarized from the 1986 remedial action program report (Rockwell, 1987).

Eleven strips of land 150 feet (46 meters) wide and 140 feet (43 meters) apart were staked and surveyed. Soil tilling commenced on June 11, 1986 followed by seed bed preparation of the cultivated areas. Soil samples were collected according to CDH protocol from the strips after tilling was completed to assess the effectiveness of the tilling in reducing plutonium concentrations. The results indicated that nine of eleven strips had been effectively remediated to below the 0.9 pCi/g (0.03 Bq/g) state plutonium guideline. Plutonium levels in two of the strips, comprising approximately 20 acres (8.1 hectares), remained greater than 0.9 pCi/g (0.03 Bq/g). These areas were tilled three more times with chisel plow rippers, after which two composite soil samples were collected. Plutonium in these samples again exceeded the 0.9 pCi/g (0.03 Bq/g) limit.

The next attempt at tilling included the use of a three bottom moldboard plow. The 20 acres (8.1 hectares) were plowed three times to a depth of 12 in (30 cm) and finished with one application of a vibrashank ripper. Analysis of ten soil samples collected from these 20 acres (8.1 hectares) indicated that the tilling had successfully reduced the average soil plutonium concentration to less than 0.9 pCi/g (0.03 Bq/g), and that the area was ready for seeding. The application of wild grass seed began on October 29, 1986 and was completed on November 17, 1986. Because the resultant cover crop of sorghum was not as heavy as desired, supplemental mulching was conducted.

Although tilling of Section 7 acreage succeeded in reducing surface soil plutonium concentrations, the fall 1986 seeding effort was deemed a failure. In June and July 1987 the 100 acres (40 hectares) were replowed to kill weeds and prepare the soil for a cover crop of sorghum (Rockwell, 1988a).

Ten acres of Jefferson County land in Section 18, immediately west of Mower Reservoir, were plowed in July 1987. Subsequent soil sampling in this area indicated that plutonium concentrations remained above 0.9 pCi/g (0.03 Bq/g). A second plowing successfully reduced surficial soil plutonium concentrations to below the 0.9 pCi/g (0.03 Bq/g) standard (Rockwell, 1988a).

In November 1987 weed control discing was conducted on the 110 acres (45 hectares) of remediated land in Sections 7 and 18. Erosion control, consisting of the planting of winter wheat and the placement of a native grass hay mulch on the surface, was also conducted during November and December 1987. Inspections during the winter of 1987-1988 revealed that little, if any, erosion was occurring. It was observed, however, that an increasing prairie dog population in Section 7 threatened to compromise revegetation efforts in some areas (Rockwell, 1988a).

Seeding of grasses on the 110 acres (45 hectares) of remediated land was completed in April 1988. By the fall of 1988 very little of the seed had germinated. Erosion protection was provided by winter wheat, annual and perennial weeds, and the remaining sorghum stubble. It was hoped that winter and spring precipitation would establish a viable native grass population in the spring and summer of 1989 (Rockwell, 1988a).

By the summer of 1989, however, native grasses were successfully established on only about 10% of the 110 acres (45 hectares). The poor outcome of the revegetation effort appears to result from the following factors (EG&G, 1990a):

- insufficient amounts and/or seasonal distribution of precipitation
- extremely rocky surfaces or clayey soils
- intense competition from weeds
- an expanding prairie dog population
- the effects of slope on soil moisture.

Specific actions have been proposed for 1990 to improve the outcome of the revegetation effort:

- reseeding using low and no tillage methods
- change of seed mixture
- irrigation during seedling establishment (via water truck)
- weed suppression and control through mowing and herbicidal methods
- hydromulching
- prairie dog suppression and control using physical and/or toxicogenic methods.

In summary, the remedial efforts conducted to date on 110 acres (45 hectares) of the Jefferson County acreage at SWMU 199 have successfully reduced soil plutonium concentrations to below the 0.9 pCi/g (0.03 Bq/g) CDH guideline. Attempts to stabilize the area through revegetation have thus far been largely unsuccessful for the reasons discussed above.

At the time of this report, remedial actions have not recommenced on Jefferson County acreage in Sections 7 and 18. Hydromulching is considered the most probable next step in the effort to establish grasses on this acreage. The use of herbicides would be very beneficial to the successful revegetation of these areas. On adjacent cultivated land where they are used, herbicides have proven very effective in suppressing and controlling weeds.

Irrigation of the remedial acreage may also be necessary in order to establish grasses. Irrigation water could be hauled by truck or piped in from another area. The RFP has discussed the subject of using treated water from Holding Pond C-2 on the plant site for this purpose with the cities of Broomfield, Westminster, Northglenn and Thornton. Agreement is sought from these cities because irrigation water runoff likely will enter Great Western Reservoir and Standley Lake, which supply water for these cities. Pond C-2, which receives surface runoff from the South Interceptor Ditch along the southern side of the RFP main production area, presently discharges through a treatment facility and a long surface pipe into the Broomfield Diversion Ditch. Water quality is monitored and the water is discharged in accordance with the National Pollution

Discharge Elimination System (NPDES) permit for the RFP, and it is expected that Pond C-2 water would be of suitable quality for irrigation of the remedial acreage. The surface pipe leading to the Broomfield Diversion Ditch could be rerouted to the remedial acreage. At present the proposal has not been approved by the cities. It may be considered, however, if the RFP constructs a surface water diversion around Standley Lake, although no such plan currently exists (Mende, 1990).

3.0 CONCEPTUAL MODEL OF CONTAMINANT FATE AND MOBILITY

Plutonium contamination of surface soils near the RFP has been attributed primarily to wind dispersal and deposition of plutonium-contaminated soil from the 903 Pad Area (Krey & Hardy, 1970). Utilizing the information obtained in past studies (Section 2.1), a conceptual model of contaminant transport and exposure pathways for SWMU 199 is presented here for use in the evaluation of the potential risks of SWMU 199 soil contamination to human health (Figure 3-1). For an exposure pathway in the conceptual model to be considered complete it must contain the following components:

- Contaminant Source: The primary current source area is the plutonium-contaminated soils of SWMU 199. Plutonium from SWMU 199 could be released to air, ground water, surface water or biota. Each of these media can subsequently become a secondary source for further releases.

- Contaminant Release Mechanism: The potential release mechanisms for plutonium from the soil to each media are presented. The main mechanisms are resuspension into air, surface water runoff, dissolution into water, and colloid formation in water. A distinction is made between primary release mechanisms (those mechanisms which release contaminants directly from the source area) and secondary release mechanisms (those mechanisms which release contaminants from secondary media contaminated by the source area).

- Transport Media: Once plutonium is released it can be transported within transport media to exposure points. The transport media can be air, ground water, surface water, or biota. Behavior and fate of plutonium in these media is important relative to exposure routes and receptors. The conceptual mode identifies both primary transport media (the media in which contaminants exist at the source area) and secondary transport media (those media in which contaminants are transported away from the source area).

- Exposure Route: Any point of potential contact with a contaminated medium is an exposure point. Exposure routes are determined according to the media contaminated and the anticipated activities at the exposure points. Exposure route can be by ingestion, inhalation, or dermal contact.

- Receptor: The receptors are the populations exposed to contaminants at the exposure points.

The conceptual model provides an overview of all the potential exposure pathways that may result from releases from and/or into each media. Some of these pathways have a higher exposure potential than others. Significant pathways are identified by evaluating the fate and mobility of the contaminant in each potential media that is included in the conceptual model.

The transformation, transport and fate of plutonium in each potential transport media is evaluated. Plutonium fate and mobility are assessed by defining the mechanisms and magnitude of potential intermedia transfers and releases, and by analyzing the chemical and physical forms, stability and reactivity of plutonium.

The magnitude of intermedia releases depends on the physical and chemical properties of the media and the plutonium. In the following sections, these properties are presented in detail for each potential transport media.

3.1 SOURCE AREA CHARACTERIZATION

The SWMU 199 area soils are considered to be the current contaminant source. A detailed description of these soils is presented in Section 2.1.2.1. The following discussions focus on soil and contaminant characteristics which affect contaminant transport. The organic matter content of the surface soils varies between 2 to 4 percent and the Ph values range from 6.6 to 8.4 (neutral to slightly alkaline). The vertical permeability of these soils is 0.06 to 0.6 in/hr (0.15 to 1.5 cm/hr). Runoff is generally rapid and water erosion potential is high. The predominant minerals of the fine soil fraction are montmorillonitic clays with calcareous materials (SCS, 1980). The climate in the SWMU 199 area is typified by strong, often gusty winds and moderate rainfall. The stronger winds blow from the west and northwest (DOE, 1980).

Plutonium (Pu) is the only significant contaminant at SWMU 199 (Rockwell, 1985a). Initial sampling indicated that plutonium concentrations in some areas were above background levels. Plutonium distribution at SWMU 199 was characterized for soil samples collected in 1977 from the site (Rockwell, 1979). Plutonium concentrations averaged 0.32 pCi/g (0.01 Bq/g) in Section 18 acreage, 0.63 pCi/g (0.02 Bq/g) in Section 7 acreage, and 0.05 pCi/g (0.002 Bq/g) in Section 6 acreage. Slightly lower values were obtained from 1985 samples from the same locations (Rockwell, 1987).

When particles containing plutonium (most often plutonium dioxide, PuO_2) are deposited on soil surfaces, they typically attach themselves by chemical and physical bonding to soil particles, especially to clays, metal dioxides and organic matter (CSU, 1974). Subsequent mobility of plutonium from these soils is determined by:

- the strength of this bonding, which is determined largely by the clay, metal dioxides, and organic matter content of soils and the type and form of plutonium; and

- the physical and chemical conditions present at the site, such as precipitation, soil moisture content, speed, frequency and turbulence of wind, vegetation cover, pH, Eh, and temperature.

These factors ultimately determine the processes that may be responsible for mobilization of plutonium to other media or exposure points. The processes could be either one or a combination of the following:

- resuspension
- dissolution/precipitation
- hydrolysis
- oxidation/reduction
- ion exchange
- sorption
- colloid formation
- complexation.

The following sections present a detailed discussion of these processes and how they affect the fate and mobility of plutonium in air, ground water, and surface water.

3.2 FATE AND MOBILITY IN THE ATMOSPHERE

Atmospheric resuspension of soil particles contaminated with plutonium is the principal mode of intermedia transfer process affecting plutonium soil contamination. Resuspension occurs as a result of wind action or soil disturbance. The resuspension factor is defined as the ratio of the air concentration to soil concentration and is expressed as per meter (m^{-1}). The resuspension factors for each contaminated section of T2S, R69W (Rockwell, 1985a) are:

- Section 6 -- 1.5×10^{-9} m^{-1}
- Section 7 -- 1.0×10^{-9} m^{-1}
- Section 18 -- 1.8×10^{-9} m^{-1}

Once resuspended in the air, the particles can move long distances depending on the wind velocity. Smaller diameter particles will be carried longer distances; therefore, the particle size of PuO_2 in soils is critical. Previous studies have shown that the distribution of plutonium by soil particle sizes at the RFP was variable, indicating the association of PuO_2 with soil mineral phases of various sizes (McDowell and Whicker, 1978). The respirable percentage of the suspended plutonium particles with diameters less than 10 micrometers (µm) (3.9×10^{-6} in) in the air is estimated to be approximately 20 to 40 percent (Whicker et al., 1974). Because of the small settling velocities associated with such particles, they can be transported long distances by air currents before settling onto the ground.

3.3 FATE AND MOBILITY IN GROUND WATER

Plutonium in surface soils may dissolve in rain water and migrate downward toward the water table. The rate of downward movement depends upon the amount of precipitation, soil properties, and the chemistry of the plutonium species in solution. Although plutonium dioxide is extremely insoluble in water, it can undergo limited dissolution in the Eh-pH range of environmental interest. Plutonium ions at +3, +4, +5, and +6 oxidation states commonly coexist in solution as Pu^{+3}, Pu^{+4}, PuO_2^{+} and PuO_2^{+2}. Plutonium +6 (i.e., PuO_2^{+2}) is the dominant form for plutonium in aqueous solutions (Allard et al., 1983). The solubility product of plutonium compounds ranges from 10^{-23} to 10^{-54} (Allard et al., 1983). Small amounts of Pu^{+4} ions formed during dissolution can undergo various reactions when solutions with these ions interact with soils and sediments. These reactions can be by ion exchange, complexation, or adsorption. When plutonium ions are sorbed onto particle surfaces, they remain fixed until the next water movement through the soil. The dissolved constituents from the sorbed particles will migrate a short distance with the next water movement and then become immobile again. As a result, the concentration of plutonium will decrease to undetectable levels within the first few centimeters of soil when there is no continuous source input. It has been shown that the complexation potential of Pu^{+4} may increase the mobility of plutonium when there are high concentrations of dissolved organic matter, carbonate, fluoride, nitrates and chlorides (Allard et al., 1983).

However, precipitation infiltrating the soil column will become significantly depleted in these parameters within the first foot of infiltration depth, causing plutonium to be immobilized within the top few centimeters of soil.

The migration rate of plutonium ions in ground water is retarded due to continuous distribution of plutonium between soil and water phases. The distribution coefficient (K_d), which is the ratio of concentrations in soils to concentrations in water, for plutonium is reported as 10^3-10^5 (Allard et al., 1983). It is not expected that plutonium will migrate very far with these high K_d values; however, it has been shown that plutonium may form colloids, or tightly and irreversibly attach to colloidal particles in ground water (ANL, 1986). These colloidal particles are unaffected by the forces that normally act to retard plutonium ion movement through the ground water system (Penrose et al. 1990).

3.4 FATE AND MOBILITY IN SURFACE WATER

Soil erosion by water may transport contaminated soils to surface waters (creeks, rivers, reservoirs). Surface water erosion of soils at SWMU 199 is estimated by the SCS at 93 to 143 tons per acre per year (209-321 metric tons per hectare per year) for bare soils and 1 to 3 tons per acre per year (2.2-6.7 metric tons per hectare per year) for vegetated areas (SCS, 1985). These figures indicate that revegetation will significantly decrease surface water erosion. Because plutonium attaches to particulate matter by electrostatic forces, its mobility in surface water depends upon the amount of suspended solids in the water. However, dissolved organics, carbonates, or other complexing agents in the water can form complexes with plutonium and increase its solubility. As a result, plutonium may stay in the dissolved phase in surface waters.

When moving water becomes stagnant, plutonium attached to particles settles out as bottom sediments. It has been shown that clay-rich sediments, such as those in impoundments near the RFP, have an extremely high affinity for plutonium in an aquatic system (CSU, 1974). As a result, the bottom sediments will immobilize plutonium considerably. However, high dissolved organic carbon, carbonate, fluoride, chloride, or nitrate concentrations along with a high percolation rate may mobilize some of the plutonium in bottom sediments to ground water. There is no evidence, however, that this process is occurring in reservoirs near the RFP. The concentrations of plutonium instead decrease to background levels at a depth of 8 to 12 in (20 to 30 cm) in the reservoir sediment columns (DOE, 1980).

It has been demonstrated that density stratification of lake waters in the summer results in a reducing environment in deeper water. The distribution coefficient of plutonium in reducing waters is threefold to tenfold lower than in oxidizing conditions. As a result, the mobility of plutonium will increase somewhat. However, the K_d values for these waters are still very high (ANL, 1986).

Resuspension of plutonium from bottom sediments is also possible by organisms that disturb the sediments. The resuspended plutonium will eventually settle back out and again become part of the sediment.

4.0 QUALITATIVE HUMAN HEALTH RISK ASSESSMENT

A qualitative human health risk assessment for SWMU 199 is presented in this section. The objectives of this assessment are to identify exposure pathways which may pose a significant threat to human health, and to identify additional information needed to perform a quantitative assessment. The qualitative assessment identifies the plausible exposure pathways and qualitative risks which are common to the following scenarios:

- No action (baseline risk assessment)
- Implementation of the remedy (workers and the public)
- Post remedy.

Additional factors which are specific to each scenario are then discussed.

At the time of this report, the quantity and quality of existing data for SWMU 199 are insufficient to perform a rigorous quantitative human health risk for the site. Due to the inherent uncertainty of qualitative risk assessment, it will not be possible in this assessment to compare the relative risks of the no action, remedy implementation, and post remedy scenarios. The media specific pathways, routes of uptake, and potential human receptors are the same for all three scenarios; however, the concentration of plutonium (source term) will decrease for the implementation and post remedy condition. Because the source term has not been adequately characterized for SWMU 199, it is not possible to calculate a risk coefficient for any of the three scenarios.

All of the data reviewed (see Section 6.0 for a list of references) indicate that plutonium is the only contaminant of concern at SWMU 199 that can be attributed to RFP historical releases. Media specific analyses of other radionuclides present at the RFP, such as americium-241, have not been performed for this SWMU. If these radionuclides do occur at SWMU 199, they would likely exist in small quantities compared to plutonium. This statement is based on the ratios of Pu/Am in the weapons grade materials handled at RFP. The initial historic ratio of Pu/Am was 15:1. As a result of the radioactive decay of plutonium-241 and subsequent ingrowth of americium-241, it is likely that the current ratio is closer to 5:1 (DOE, 1988). No americium measurements are available for SWMU 199; however, since americium produces almost twice the internal dose as plutonium (ICRP, 1979), determination of its magnitude and extent must be accomplished for a quantitative risk assessment. Since no values are available for americium, its contribution to this qualitative assessment cannot be addressed. The Pu/Am ratio does indicate that the added risk from the presence of americium would not increase the risk at SWMU 199 less than one order of magnitude. Therefore, only plutonium will be addressed in this risk assessment.

4.1 CONCEPTUAL APPROACH

Since the historic source of plutonium contamination to SWMU 199 has been effectively eliminated by remedial action at the 903 Pad, this assessment is based on the assumption that the plutonium present at SWMU 199 represents the highest possible concentration that will be available for human receptor impact. Concentrations in the soil will be reduced over time by either natural processes (soil erosion, vertical downward migration, fugitive dust), or remedial action (tilling and revegetation) for the remedy implementation and post-remedy scenarios.

This is a qualitative risk assessment that uses hazard rankings (Section 4.5.3) instead of plutonium concentration values, transport equations and receptor dose calculations to convey the relative magnitude of specific media occurrence, release probabilities, potential routes of uptake and the ultimate impact on a human receptor.

The EPA Risk Assessment Guidance (RAG) document defines the following four elements for a completed exposure pathway as follows (EPA, 1989b):

- A source and mechanism of chemical release to the environment
- An environmental transport medium for the released chemical (air, ground water, etc.)
- A point of potential human or biota contact with the contaminated medium (exposure point)
- A mode of uptake at the exposure point (ingestion, inhalation, or dermal contact).

If any of these elements are absent, there is no resultant human exposure and consequently no risk. For the purposes of this assessment, the term exposure pathway will be used only when all four of these elements are present.

The risk assessment will be developed as follows:

Toxicity Assessment (Section 4.3)
The human health risks associated with radiation exposure are briefly described, with emphasis on exposure to plutonium.

Source Term (Section 4.4)
The source term describes the amount of contaminant (plutonium) found in the environment. For SWMU 199, the source term corresponds to plutonium concentrations in soil. The concentration of plutonium in the soil affects the magnitude of any release into other media, for example, the lower the concentration of plutonium in soil, the lower the airborne plutonium concentration that can be generated from the soil.

Exposure Pathways (Section 4.5)
The importance of potential exposure pathways is assessed by estimating the magnitude of potential exposure, the frequency and duration of these exposures, and the media-specific pathways by which humans are potentially exposed. The magnitudes of potential exposures are based upon the media-specific (soil) contamination being a contamination source for other media.

Exposure Routes (Mode of Uptake) (Section 4.6)
The various routes of plutonium uptake by humans and other organisms are identified and ranked by relative importance to the risk assessment. The risks associated with potential points of human contact are qualitatively assessed based on all identified exposure pathways. A description of the behavior of plutonium in biological systems is included in this section.

Risk Characterization (Section 4.7)
The concepts developed in preceding sections are combined into a site-specific risk characterization, which evaluates the concentration of plutonium in each media, its likelihood for

transport to other media, and its likelihood to impact a human receptor. All potential exposure pathways are systematically examined, and those which do not meet the criteria of a completed pathway are eliminated from the risk assessment.

4.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)

In the revised National Contingency Plan (NCP: 53 FR 51394) and the CERCLA compliance with other laws requirement (EPA, 1989c), several different types of ARAR requirements are identified with which remedial actions must comply: (1) chemical specific requirements, (2) action specific requirements, and (3) location specific requirements. The most stringent ARARs for plutonium are found in the CDH regulations. The site specific soil ARAR identified for SWMU 199 is the CDH plutonium in soil guideline of 0.9 pCi/g. The Colorado Water Quality Control Commission has established a plutonium standard for Walnut and Woman Creek of 0.05 pCi/l (0.002 Bq/l), significantly lower than the EPA standard of 15 pCi/l (0.56 Bq/l) total alpha activity. A Memorandum of Understanding and Mutual Cooperation Agreement regarding public exposure to airborne plutonium between DOE and CDH also exists. Offsite airborne levels of plutonium to 0.02 pCi/m^3 (0.0074 Bq/m^3). All air monitoring data reviewed from air sample locations potentially impacted by SWMU 199 are well below this standard. DOE Order 5400.5, Radiation Protection of the Public and the Environment, specifies the same airborne plutonium public exposure limit as the CDH. It is noted here, and discussed in Section 4.6, that the airborne standard is based on Class W (soluble) plutonium, while the majority of plutonium at SWMU 199 is Class Y (insoluble) plutonium, which has an ARAR of 0.04 pCi/m^3 (0.0015 Bq/m^3) (Wick, 1967).

4.3 TOXICITY ASSESSMENT

In order to evaluate the potential risks posed by plutonium, it is important to understand the toxicity hazards of radiation for different exposure routes. Radiation is defined as the transfer of energy from one place to another. Heat, sound, and light are radiation but do not carry enough energy to break the atomic bonds of molecules; however, ionizing radiation, when interacting with matter, has sufficient energy to break the atomic bonds of molecules, and produce (emit) an ejected electron and a positively charged ion. Ionizing radiation may be in the form of particles or electromagnetic waves.

Plutonium is primarily an alpha particle emitter. An alpha particle is essentially a helium nucleus without orbital electrons. It is composed of two protons and two neutrons with a charge of plus two. Since these alpha particles have a relatively large mass and +2 charge, they react strongly with matter, and create a large amount of ionization in a very short distance. However, even alpha particles with the high kinetic energies of plutonium travel only about 1.6 inches (4 cm) in air, and can be stopped by a piece of paper, or the outermost layer of dead skin. Alpha particles therefore do not present an external exposure hazard. These same properties do however produce much more cellular damage than an equivalent amount of gamma energy, if both alpha and gamma are internally deposited. The range of penetration of a plutonium alpha particle in tissue is approximately 100 um (3.9×10^{-3} in), indicating that an alpha particle retained in the body will deposit 100 percent of its ionizing radiation to localized tissue. The concepts developed in this section describe the various ways plutonium can enter the body (exposure routes), and the relative risk of each mode of uptake. For the purposes of this risk assessment, it is assumed that the insoluble form of plutonium, plutonium dioxide (PuO_2), will be the predominant radionuclide available for biological uptake.

In general, there are two distinct human hazards presented by radiation, those of external and internal radiation exposure. External radiation exposure is due mainly to gamma ray emissions from radioactive decay. Although plutonium does produce x- and gamma rays, they are very weak and only comprise a small percentage of the total energy emitted. Therefore, this risk assessment does not consider external radiation exposure as a hazard from SWMU 199. Plutonium does, however, present an internal radiation hazard, primarily from inhalation. The inhalation of plutonium can lead to the deposition and retention of radioactivity in the lung, and produce continual, localized internal irradiation of lung and other body tissues for extended periods of time.

The levels of plutonium present in the soil at SWMU 199 are very low, but have not been adequately characterized (Section 4.4). The health effects that this qualitative risk assessment will focus upon are the low levels of internal exposure that workers and the public could potentially receive from SWMU 199, mainly by the airborne pathway. Such low levels of plutonium exposure can cause genetic and somatic (non-genetic, i.e. cancer) effects, which have a long latent period. These long-term effects are due to DNA damage. The body has many defense mechanisms against such damage, including repair of the DNA, immunological defenses, and the death of a cell. Ionizing radiation can also induce a neoplasm, the uncontrolled growth and proliferation of a group of cells (cancer).

4.4 SOURCE TERM

The initial step of this assessment involves data evaluation of the source term at SWMU 199. The source term for the site is considered to be approximately 350 acres (142 hectares) of plutonium contaminated surface soils just outside the eastern boundary of the RFP. Historical radiological site data relevant to a human health evaluation were collected from DOE and CDH sources. These data were evaluated for the concentration of plutonium present in all media.

Extensive soil sampling has not occurred at SWMU 199. In some cases, the quantitation limits and detection limits for plutonium were not included in the referenced documents. It is believed that most of the published data have not been through a rigid QA/QC analysis. It is also evident that sampling procedures for all media have differed between various sampling agencies. Because of these uncertainties, a numerical value cannot be assigned to the source term at SWMU 199 with any certainty. Section 4.14 discusses additional data needed for a reliable determination of SWMU 199 source term to support a quantitative risk assessment.

4.5 EXPOSURE PATHWAYS

The identification and assessment of exposure pathways is accomplished by characterizing all potential contaminant release mechanisms which may contribute to a completed exposure pathway to human and environmental receptors. The release mechanism analysis evaluates the possible migration of the chemicals of concern, taking into account their physical and chemical properties that affect environmental fate in the various site media. Certain site characteristics such as hydrogeology, soil organic carbon, climate, and vegetative cover may also have a significant influence on the migration potential. Current and future use of the site (farming, grazing, use as open space) may also determine the current and future exposure scenarios.

4.5.1 Identification of Release Mechanisms

Possible release mechanisms of plutonium from soil at SWMU 199 are identified in the conceptual analysis as shown in Figure 3-1 of Section 3.0. Primary release mechanisms include:

- Fugitive dust-wind erosion and recreational use
- Surface runoff
- Infiltration/percolation
- Biotic uptake
- Tracking by insects, birds and animals.

Figure 3-1 also includes an assessment of the secondary release mechanisms present at SWMU 199. These secondary release mechanisms include:

- Recreational use -- resuspension of settled dust
- Direct fugitive dust
- Settled dust -- plants
- Settled dust -- soil (leading to possible airborne dust)
- Settled dust -- water
- Biotic uptake of surface water
- Surface water deposition
- Surface water irrigation
- Surface water infiltration
- Surface water evaporation leading to possible airborne dust
- Ground water seepage
- Ground water pumpage.

4.5.2 Identification of Transport Media

A physical examination of SWMU 199 and a review of available historical data for the site indicate that the only primary transport media for plutonium is the surface soils (Figure 3-1). Numerous possible primary release mechanisms are listed above, but it is the fugitive dust release mechanisms that can cause the greatest impact on the secondary transport media of air. Other potential transport media for plutonium include surface runoff, groundwater, and biotic uptake. The following discussion provides a more detailed description of soil reentrainment, and some description of the surface runoff, groundwater, and biotic uptake transport mechanisms at SWMU 199.

4.5.2.1 Factors Affecting Airborne Reentrainment

The general principles of atmospheric fate and mobility of plutonium are stated in Section 3.1.2. However, a further explanation of atmospheric transport parameters is offered in this section because inhalation of plutonium particles from surface deposition off-site is considered to be the most probable means of human exposure adjacent to the site. It is important to understand the mechanisms of contaminant transport before considering the corrective actions needed to reduce or eliminate transport. To quantitatively assess the environmental impact and human health risk resulting from the contamination under pre-remedy, remedy implementation and post remedy conditions, meteorological data specific to the site should be collected (Section 4.14).

Two primary mechanisms are associated with the initiation of particle movement. Direct action of air moving past a particle may exert enough force to accelerate the particle, causing it to roll along the surface or to be lifted up and moved in the air stream. A second mechanism of initiating particle movement is through the impact of airborne particles with particles on the ground. Particles on a solid surface which have chemical and physical properties different from the base material have adhesive contact to the substrate. For resuspension to occur with this scenario, the force on the particle must be equal to or greater than the force holding the particle to the surface. Several factors are known to influence particle cohesion:

- particle material
- size
- shape
- surface roughness
- relative humidity of the ambient air
- presence of electrostatic charge
- nature and physical characteristics of the substrate.

The primary meteorological factors which influence the resuspension of material from ground deposits are wind and ground surface moisture. The amount of material that can be carried in the air currents is dependent on the density, velocity, and viscosity of the air.

Particles that are dislodged from the ground surface can then move in three ways: suspension, saltation, and surface creep. Suspension occurs when upward wind eddies counteract free fall, allowing transport of the particle at the average forward speed of the wind. These particles are generally less than 0.1 millimeter (mm) in diameter and are redeposited via rainout or gravity after the wind subsides. Particles between 0.1 mm and 0.5 mm in diameter move by a series of short bounces called saltation. Larger particles between 0.5 mm to 2 and 3 mm in diameter can roll and/or slide along the surface in what is called surface creep. Particle movement predominantly occurs by saltation. Successful revegetation of the contaminated acreage can reduce all three methods of particle transport.

Due to the elapsed time since the last known releases to SWMU 199 from RFP (1970), it can be assumed that any free plutonium, (i.e., that available for air transport in the soil environment) has been subject to weathering and aging. Previous RFP studies (Krey and Hardy, 1970; Whicker et al., 1974) and general textbooks (Wick, 1967) support this statement concerning the behavior of plutonium in the environment. Thus, the deposited plutonium is assumed to have become an integral part of the surface soil, and that it behaves according to the concepts developed for soil erosion. Among the parameters which most influence the movement of soil by wind are the space and time variation of the soil particle size distribution. In considering particles of plutonium, some caution must be exercised. Although it is currently unknown what fraction of the plutonium in resuspension consists of unattached particles and what fraction is attached to host soil particles, a large portion of the plutonium can be attached to resuspended soil particles. Based upon a particle-size study using impactor samples, it was concluded that plutonium on individual soil particles containing plutonium were much smaller than the impactor-size diameter of the fraction collected (Langer, 1986). The plutonium present in this study, assumed to be PuO_2, had particle diameters of less than 0.25 μm, and if found in a free form, would be of a respirable particle size. However, since plutonium is found in an agglomeration with soil, it is much less likely to be available for deposition in the lung. Nevertheless, the conservative assumption of this qualitative risk assessment is that all airborne plutonium is of a respirable particle size.

It is very likely that fixation of the plutonium has occurred at SWMU 199 through all of the above-described processes, and that the fixed material is dispersed in a surface layer several centimeters deep. As such, since environmental conditions produce continuous changes in surface layer characteristics, a simple relationship between wind speed and the resuspended material has little validity. However, data are available that indicate a resuspension factor of 10^{-10} to 10^{-8} per meter (m^{-1}) for a fine powder from prairie terrain at measured wind speeds of approximately 2.2 to 45 mph (1 to 20 m/sec). Resuspension rates approximate 10^{-10} per second at 2.2 mph (1 m/sec), and increase rapidly to 10^{-8} per meter at 11.2 mph (5 m/sec) where they appear to reach a plateau (Rockwell, 1985b).

An average wind speed of approximately 9 mph (4 m/sec) is assumed for RFP. The Rocky Flats Risk Assessment Guide (Rockwell, 1985b) uses a resuspension factor of 10^{-10} m^{-1} for reentrained soil. This value is an order of magnitude lower compared to values discussed in Section 3.0 for SWMU 199, which is indicative of the different type of vegetative cover present at SWMU 199. Even though ten times more surface soil may be reentrained at SWMU 199 than for a similar sized plot of undeveloped land at RFP, the potential impact on human receptors appears low, based on measurements by air sampling devices downwind of SWMU 199.

4.5.2.2 Plutonium Uptake in the Food Chain

As described in Section 3.1.3, plutonium forms relatively insoluble compounds in the environment and is therefore not considered ecologically mobile. Since plutonium has no known biological function, it can only be passively incorporated into organisms, mainly by physical processes such as surface contact, inhalation, and ingestion of plutonium adsorbed to the surfaces of plants and zooplankton.

Food-chain transfer of plutonium does represent a potential exposure route. A critical parameter used in this determination is K_{ow} (logarithmic octanol-water partition coefficient). This is a good indication of how readily an organism will take up a particular compound, and is a general predictor of bioaccumulation in the oils of fish or the fat of animals. The K_{ow} is related to water solubility and bioconcentration factors for aquatic and terrestrial life.

In an aquatic ecosystem, the supply of basic compounds such as carbon dioxide, and of elements such as oxygen, calcium, hydrogen, and nitrogen, is contained either in solution or is held in reserve in the bottom sediments. These nutrients are absorbed and metabolized through the utilization of solar energy by two main types of food producing organisms: rooted or large floating plants, and minute floating plants called phytoplankton. All literature reviewed indicates that the plutonium K_{ow} for water and uptake of plutonium by terrestrial plants is extremely low, and that root uptake of plutonium is negligible.

As a general rule, radioisotopes present in soil sediments can pass into the root system of plants in the same manner as nonradioactive isotopes of the same element. The element may or may not be required for normal metabolism, and some elements (e.g., iodine, cobalt, uranium, and radium) are known to be present in plants although they serve no metabolic function. However, literature reviewed indicates that even when plutonium has been applied in a water-soluble form and mixed into surface soil, plutonium is strongly excluded from uptake in the first crop plants grown on that plot. The relative concentration factor expressed as parts per million in dry plant material/part per million in dry soil has been measured at less than 0.01% for plutonium (Menzel, 1965). This value has been replicated in a study of sheep grazing in a marsh estuary near Sellfield, England (Ham, 1989).

Radioactive substances can pass directly to the food chain by foliar deposition. The radionuclides may then pass directly to grazing animals or man as superficial contamination, or they may be absorbed metabolically from the plant surface. The significance of plant surface contamination varies with the growing season, since the potential risk due to direct contamination of crops is obviously greater just before a harvest or during active grazing by stock animals. Conversely, the potential risk may be lowest in winter months when there are no standing crops, although it is possible that even during these months direct fallout on the basal structure of grasses in permanent pastures may be stored until the following spring. Retention of this type will be greatest for plants that develop a mat of basal parts, old stems, and surface roots.

The significance of foliar contamination of plants will also depend on the structure of the plants and the role of the various parts of the plant in relation to the dieting habits of man. Wheat plants have a shape that tends to maximize entrapment of settled fugitive dust. Other cereal grains and grasses also have relatively high foliar retention.

Foliar contamination can be removed by rain, other weathering effects, and by drying and dropping of plant parts (field loss). Chamberlain (1970) has examined data from a number of investigators and found the field loss during the growing season to be about 0.05 percent per day.

4.5.2.3 Surface Water

This transport media for plutonium depends almost totally on the amount of soil erosion by rain at SWMU 199 since the solubility of plutonium is so low. Once plutonium contaminated soil is picked up by surface waters, plutonium could migrate along slopes and drainages on-site. Currently, there are no perennial surface waters located at SWMU 199. It is also possible that heavy rains could cause particulate matter containing plutonium to move some distance, be redeposited on the soil, and create availability for fugitive dust wind erosion. Numerous studies have documented that surface runoff can cause plutonium to migrate, albeit a very short distance. This probability of occurrence is low to moderate, since all 350 acres (142 hectares) do have some form of vegetative cover. The likelihood that this transport media would produce an impact on a human receptor is negligible at SWMU 199.

4.5.2.4 Ground Water

Plutonium has only been found in ground water in one well (Well 4-86) at RFP. This is almost exclusively due to the fact that plutonium is not very soluble in water media, and is highly adsorbed to clays and other soil particulates. The probability of plutonium transport in ground water through infiltration/percolation is therefore believed to be negligible. Ground water monitoring wells have been developed downgradient of the RFP, but not downgradient of SWMU 199. Site-specific soil and ground water quality data are required to conclusively determine that SWMU 199 is not impacting ground water.

4.5.3 Potential Exposure Pathways at SWMU 199

Potential exposure pathways will be addressed in this section. As illustrated in Figure 3-1, various possible transport media exist at SWMU 199 along with their associated primary and secondary release mechanisms. Section 3.0 describes the contaminant fate and mobility assessment of plutonium in the environment, and concludes that plutonium is highly insoluble in ground water and surface water, and bonds strongly to soil surfaces. As stated in Section 4.1, a completed exposure pathway must exist for a hazard to be conveyed to the receptor. Many of the potential transport media and release mechanisms identified thus far do not form a completed pathway, and therefore do not pose a risk to human health. The only credible completed exposure pathway for SWMU 199 is shown in Figure 4-1. Although other pathways are addressed for the sake of completeness, they are not considered in the determination of qualitative risk.

Primary and secondary release mechanisms are grouped with transport media (Table 4.1) to determine their probability of transporting plutonium in the environment based on the following probability ranking:

1. High -- historic records or physical characteristics of SWMU 199 indicate that plutonium has a high probability of occurring in this release mechanism and/or transport media

2. Moderate -- a possibility exists that plutonium may be released by this mechanism or transported by this media (airborne, fugitive dust, surface runoff).

3. Low -- the likelihood is that this release mechanism or transport media does not provide any significant possibility of release or transport in the environment (fugitive dust).

4. Negligible -- all historic data and physical characteristics of plutonium indicate that this is not a credible release mechanism or transport pathway for plutonium (ground water, surface water, biotic uptake).

4.5.3.1 Soil Media

Much of the soil data reviewed indicate that natural processes such as biological activity, weathering and percolation will cause plutonium to move vertically downward in the top few centimeters of the soil column. Section 3.0 of this document describes some of the factors most important to plutonium transport in soil. One of the most important factors is the distribution coefficient (K_d). This term reflects the ability of ions and molecules to adhere to solid surfaces. The fine particles of soil and sediment have enormous surface areas relative to their volumes, and carry electric charges. Ions and molecules can bond to these surfaces by forcesthat range from those due to weak residual electric charges to strong chemical bonds. Typical K_d values (unitless) for plutonium are 10^3 to 10^5 indicating its high potential for immobilization by soil

(Allard et al., 1983). This has an important bearing on assessment of the fate and transport of plutonium in the environment.

The concepts of soil reentrainment in air for SWMU 199 are discussed in Section 3.0 and 4.5.2.1. One significant factor is that reentrainment for the RFP is estimated to be 10^{-10} m^{-1}, while reentrainment for SWMU 199 is calculated to be 1.0 - 1.8 x 10^{-9} m^{-1}, almost an order of magnitude higher (Rockwell, 1985a). This may be attributed to the reduced vegetative cover of the area.

Soil sample studies measuring existing plutonium concentrations at SWMU 199 have been reviewed. The data presented are subject to question and probably would not withstand QA/QC validation. However, this data does provide an indication of the order of magnitude of the plutonium concentration present in the soils. Soil sampling at SWMU 199 was performed during 1977 and 1985 (Rockwell, 1987). The results indicated a decrease in plutonioum concentration in 1985 versus 1977 for all samples in the survey. The decrease was attributed to the weathering of the soil and vertical migration of plutonium in the soil. However, these results appear inconclusive because: (1) the 1985 survey took one sample per 10 acres (4 hectares) compared to one sample per 0.2 acre (0.08 hectares) in 1977, which averages to 50 samples per 10 acres; and (2) different analytical laboratories utilzing different radiochemical procedures for plutonium extraction and counting were used.

The concepts developed in this document indicate that the soil pathway for SWMU 199 soils can produce fugitive dust from wind erosion, leading to an inhalation exposure route for a human receptor. The direct air pathway, as well as resuspension after redeposition on the soil, will be retained in this qualitative risk assessment.

The following soil pathway will be eliminated since ingestion is not a credible pathway for plutonium exposure at this SWMU:

Surface Soils → Fugitive Dust → Air → Settled Dust (to soil)
Surface Soils → Fugitive Dust → Air → Settled Dust (to Water)

4.5.3.2 Surface Runoff Media

The only credible release mechanism involving surface runoff would be surface runoff carrying suspended plutonium particles that subsequently deposits these soils in a dry area. Only in this manner could fugitive dust be generated by wind erosion. This pathway is not likely to produce any measurable amounts of airborne plutonium due to the low activity present in the soil and the physical nature of plutonium transport in the environment. Therefore, it will not contribute to a completed exposure pathway and will not be retained in this risk assessment. The following surface runoff pathways will therefore be eliminated for SWMU 199:

Surface Soils → Surface Runoff → Surface Water → Biotic Uptake
Surface Soils → Surface Runoff → Surface Water → Deposition
Surface Soils → Surface Runoff → Surface Water → Irrigation
Surface Soils → Surface Runoff → Surface Water → Infiltration

4.5.3.3 Ground Water Media

An extensive ground water monitoring system has been installed on the RFP. The well locations were selected to monitor ground water in areas where potential contamination might be expected. Well locations are near holding ponds, evaporation ponds, and creek beds. Monitoring wells in the buffer zone along the eastern boundary of the RFP have been sampled, and only one instance of plutonium levels above background was detected in any of the wells. This suggests that the soil/sediment column is a good medium for binding plutonium and preventing it from reaching ground water. Although no direct sampling data are available concerning plutonium transport from the land areas of SWMU 199 to ground water, it can be inferred from the RFP on-site data that this pathway will not contribute to a completed exposure pathway. Therefore, consideration of the following pathway will be eliminated from the qualitative risk assessment:

Surface Soils → Infiltration/Percolation → Ground Water → Seepage and Pumpage

Site-specific data should, however, be collected for SWMU 199 to confirm that this is not a viable pathway.

4.5.3.4 Biotic Uptake

Due to the insoluble nature of plutonium, its uptake in the biota by transport through the food chain is not likely. Indicator plants and animals have been identified, sampled, and found to contain normal background ranges of plutonium. Insects are also a potential source of bioaccumulation, but no sampling data are available that provide the results of potential bioconcentration. Prairie dogs heavily populate SWMU 199, and their burrowing activities produce a vertical redistribution of the plutonium in soil. This activity enhances "tilling action" and effectively dilutes the plutonium concentration in soil (Winsor, 1980). However, this prairie dog activity negatively impacts the success of the revegetation effort. No sampling data are available that describe plutonium uptake and bioaccumulation by these prairie dogs.

The literature reviewed for this document (Section 6.0) indicates that biotic uptake for plutonium is highly unlikely at SWMU 199. Therefore, the following pathway will be eliminated from the qualitative risk assessment:

Surface Soils → Biotic Uptake → Biota

4.5.3.5 <u>Tracking</u>

Tracking (transport and redeposition) of plutonium by organisms living on or migrating through SWMU 199 is considered insignificant for the transport of plutonium when compared to movement by wind and surface runoff. The following pathway will therefore be eliminated from further consideration:

Surface Soil → Tracking

4.5.3.6 <u>Recreational Use</u>

Jefferson County has dedicated its 250 acres (101 hectares) of SWMU 199 to the Jefferson County Open Space program. County regulations allow public access to Open Space lands for hiking, mountain bike riding and horseback riding. At the present time, however, public access to the SWMU 199 acreage owned by Jefferson County is restricted, and recreational usage is not allowed. If the land is opened to recreational usage in the future, it is believed that the permitted activities would generate negligible amounts of reentrained surface soil (dust), and therefore present a negligible risk from airborne plutonium to recreational users.

At the time of the Settlement Agreement (1985), the City of Broomfield intended to use its 100 acres (41 hectares) of SWMU 199 for future expansioin of Great Western Reservoir. To date, the reservoir has not been expanded. The land has remained in its original state, and acts as part of a buffer zone around the reservoir. Public access is restricted. The City of Broomfield has no definite plans for future usage of their SWMU 199 acreage (Broomfield, 1990).

4.5.4 Summary of Transport and Release Mechanisms

The only credible transport and release mechanism for SWMU 199 is wind erosion of the surface soil which produces fugitive dust. This dust may then be transported to human receptors in a form available for uptake as follows:

Surface Soil → Fugitive Dust → Air → Inhalation

4.6 EXPOSURE ROUTES

Various modes of uptake, including inhalation, ingestion, and dermal contact, can lead to internal radiation exposure. The two primary modes of plutonium uptake that would lead to internal radiation exposure are the inhalation and ingestion of radioactive materials. Dermal contact is not a significant mode (Section 4.3). The estimation of organ burden and exposure, as well as of the resulting dose rates and doses, due to uptake by these pathways is based on the use of mathematical models which depend on many parameters. Publications ICRP 30 (ICRP, 1979), ICRP 31 (ICRP, 1980), and ICRP 48 (ICRP, 1988) provide the criteria necessary to calculate the committed effective dose equivalent for both occupational workers and the general public. This section will show that the magnitude of the dermal contact/ingestion pathway is insignificant when compared to inhalation.

4.6.1 Inhalation

The inhalation of an aerosol carrying radionuclides is a potential mechanism for damage to the respiratory tract as well as a possible pathway for the translocation of inhaled radioactive material to other reference organs. The complexity of the biological phenomena which govern transmission and elimination of such material complicates the assessment of potential health effects due to inhalation of radioactive material. Factors which must be included are:

1. The fractional deposition of inhaled material in the respiratory tract depends on properties of the aerosol size and mass distribution, chemical form, and charge, as well as on the breathing rate and such physiological characteristics of the lung as its

surface properties and configuration. For the purposes of this qualitative risk assessment, it is assumed that 100 percent of the plutonium is available for uptake.

2. The duration and extent of the exposure depends on the biological and physical mechanisms which transport the deposited material and its decay products within the body. These include the various clearance paths, the nuclide half-lives, the chemical form, the solubility, and the degree of retention in each reference organ of interest.

3. The dose depends on the time integrals of the activity of both parent and daughter in the organ, the organ mass, the emitted energy of each nuclide, and the fraction of that energy absorbed by the organ tissues.

Inhalation is the most common pathway by which plutonium can cross the barriers of the body and penetrate into and across living cells. The aerodynamic particle size of the aerosol, which accounts for not only the sizes of the particles but also their density and shape, determines the fractional deposition and sites of deposition in the respiratory tract. The bioavailability of plutonium adsorbed to particles often depends on this aerodynamic particle size. Particles with a diameter greater than 5 microns usually become imbedded in the mucous of the pharynx, trachea, or bronchi. The mucous is swept up the respiratory tract and swallowed. The absorption efficiency of these large particles depends on the gastrointestinal absorption efficiency, which is extremely low for plutonium (Section 4.6.2). Consequently, inhaled particles that are subsequently ingested reduce the magnitude of the inhalation pathway. The subsequent rates and routes of clearance; the translocation to, deposition in, and rate of clearance from other tissues; and the excretion in urine and feces of plutonium depend on particle size, solubility, density, shape and other physicochemical characteristics of the plutonium aerosol. The biological half lifes in the lung are defined for various solubility classes as Days (0.5 days), Weeks (50 days) and Years (500 days). The ICRP has determined the solubility class for various plutonium compounds (ICRP, 1979). These are:

- Class D (days) - no plutonium compounds
- Class W (weeks) - all plutonium compounds except plutonium dioxide (PuO_2)
- Class Y (years) - plutonium dioxide (PuO_2)

4.6.2 Ingestion

The ingestion of radioactive material (soil, water) represents another pathway by which radioactivity may be transferred internally to blood and, subsequently, to other organs. While a description of this pathway is simpler than for inhalation, due to the direct deposition of the ingested material into the gastrointestinal (GI) tract, treatment of the balance of the biological-physical processes involved is affected by the same uncertainties of biological parameters as were discussed for the inhalation model. In the ingestion model the critical transfer mechanism is the absorption of radioactive material into the systemic blood from the small intestine. However, the gastrointestinal tract provides a substantial barrier to the uptake of plutonium ingested with food or water. Inhaled plutonium will also be cleared from the lungs to the gastrointestinal tract, so gastrointestinal absorption is a consideration, although it is a negligible pathway in regards to risk. Values for the fraction, F_1 (GI absorption factor), of ingested radioactivity transferred to blood have been studied in animals and to a limited extent, are still subject to large uncertainties which strongly affect projected doses to the reference internal organ. The EPA lists an F_1 value of 1.0 E-05 for Class Y plutonium-239 (DOE, 1988). This indicates that the ingested plutonium will not easily transfer to other body compartments. Class Y plutonium refers to the solubility and body retention of the radionuclide. This class is insoluble in the body and, if breathed in, tends to be retained in the lungs for months to years. However, if ingested, Class Y plutonium tends to pass through the body with no biological uptake. As stated previously, PuO_2 is considered to be insoluble in the body, and thus is classified as Class Y plutonium. This qualitative risk assessment makes the assumption that the amount of Class W plutonium (more soluble in the body) is negligible when compared to the amount of Class Y plutonium found at SWMU 199.

4.6.3 Dermal Contact

Plutonium-239 and plutonium-240 are alpha emitters and hence only present a biological hazard if they are transferred into a biological system. The dermal contact human transfer pathway for plutonium would involve skin contamination and subsequent transfer into the body through an open wound or by ingestion. Unbroken skin has been shown to be an effective barrier to the penetration of plutonium, and dermal absorption coefficients cited in the literature are on the order of 5×10^{-5} (NRC, 1988). It is highly unlikely that soluble plutonium is present at SWMU 199 in a concentration that would lead to transfer through an open wound by skin contamination. Since the GI absorption factor is 1.0×10^{-5} for class Y (insoluble) plutonium, human biouptake of plutonium soils by the dermal contact pathway and subsequent GI absorption is not plausible.

These risk values are restated here to reinforce that the inhalation pathway produces by far the principal hazard from SWMU 199. Because of plutonium's low soil mobility and water insolubility, the additive risk associated with plutonium soil/water ingestion are insignificant when compared to the health risk associated with plutonium inhalation.

4.7 RISK CHARACTERIZATION

A qualitative risk assessment is a systematic identification of potential hazards of events that could result in undesirable consequences, and is basically subjective. The main disadvantage of a qualitative approach is that it is difficult to make specific numerical comparisons among the risks of different events or scenarios. However, as shown in Table 4.1, hazards can be grouped by relative importance into risk categories (i.e., critical, marginal) and linked with frequency categories (i.e., high, moderate, low, negligible). Pathways and release mechanisms that have a critical importance to the risk assessment have a high probability of impacting a human receptor. Those that have a marginal importance have a very low probability of impacting a human receptor.

4.7.1 Risk Characterization Process

The risk characterization presented here evaluates the magnitude of the concentration of plutonium in each media, its likelihood for transport to other media, and its likelihood to impact a human receptor. The concepts developed in preceeding sections are utilized to determine the magnitude of risk based on the following ranking:

1. High -- A significant potential hazard to human health exists based on historical data, physical characteristics and/or present conditions.

2. Moderate -- It is possible that plutonium will be measured at the receptor point by using maximum credible assumptions of release mechanisms and exposure pathways.

3. Low -- It is highly unlikely that a hazard to human health exists, using maximum credible assumptions of release mechanisms and exposure pathways combined withhistorical data, the physical characteristics of plutonium transport and present conditions.

4. Negligible -- The release mechanisms and completed exposure pathways do not exist to provide risk to human health.

4.7.2 Physical Model

Providing a reasonable estimate of internal radiation doses due to inhalation and ingestion requires that a consistent model for both the respiratory and gastrointestinal tracts be employed. While a large amount of theoretical and experimental work on such models has been done, the most widely accepted models that provide reasonable estimates of internal radiation doses have been those developed by members of the respective ICRP working groups.

The proposed ICRP Task Group on Lung Dynamics (TGLD) model for the respiratory tract has been well documented. Parameters suggested for use in the model have been extensively reviewed and, to some extent, improved in ICRP publications (ICRP, 1979; ICRP, 1980). The ICRP TGLD proposed model comprises three major respiratory compartments: the nasopharyngeal, the tracheobronchial, and the pulmonary. Each of these major compartments is divided into subcompartments corresponding to various transfer mechanisms, which are treated as essentially independent processes. In addition, the associated lymph nodes are appended to the pulmonary compartment in one of the transfer chains. Direct deposition through inhalation occurs to the three major compartments, with the fractional deposition in each being a function of the aerosol properties. Subsequent transfer and/or clearance is governed by parameters specified for each subcompartment.

For the calculation of soil/water ingestion, the ICRP gastrointestinal tract model can also be used to determine internal exposure. The model comprises a four-compartment tract consisting of the stomach, small intestine, and lower and upper large intestine. The times involved in the passage of material through the stomach and small intestine (the only compartment from which transfer into the blood occurs) are negligible compared to the residence times associated with most Class Y compounds in the lung and can be neglected when considering doses due to ingestion of insoluble plutonium.

4.7.3 Risk From All Modes of Exposure

The chemical forms of plutonium found in the off-site soils at RFP are highly insoluble both in the environment and in the human body. Based on a review of exposure durations and modes, it appears that the dose equivalent is negligible and poses a very low risk pathway in the qualitative model. Developing these concepts in tabular form, biological uptake mechanisms from all release pathways can be ranked from the most likely to the least likely:

Exposure Route

- Inhalation
- Inhalation then ingestion
- Ingestion of soils
- Bioaccumulation
- Dermal contact
- Ingestion of drinking water.

The last four routes are considered negligible from a risk standpoint. In lieu of performing a calculation based on the concepts of Section 4.6, a qualitative comparison of pathway specific risk is provided by the EPA (EPA, 1990). The EPA has developed the following media-specific concentration-based unit risk factors for age-averaged lifetime excess total cancer per unit daily intake (exposure for 70 years) of Class Y ^{239}Pu:

	Air 1 pCi/m^3	Drinking Water 1 pCi/L	Soil Ingestion 1 pCi/g
Cancer Risk Factor[1]	2.6 E-2	1.6 E-6	8.4 E-8

[1] The media-specific risk factors are based on standard man (155 lbs [70 Kg]) intake rates of:

- 706 ft^3/day (20 m^3/day) inhaled air
- 0.6 gal/day (2.2 l/day) ingested liquid
- 2.2 x 10^{-4} lbs/day (0.1 g/day) ingested soil.

These values assume that all daily media exposure is derived from contaminated airborne fugitive dust (706 ft^3), surface water/surface runoff (0.6 gal water), and soil (2.2 x 10^{-4} lbs) and that exposure occurs continuously for a 70-year lifetime.

These unit risk factors use the same basic approach as other models (DOE, ICRP); however, the EPA uses the model to derive risk from each type of media. These risk factors reinforce the premise that inhalation of plutonium (pCi/m^3) has a much greater risk factor than from ingestion of water (pCi/l) or soil (pCi/g). Since it has been shown that the air pathway from SWMU 199 produces a negligible risk to the public, all other pathways must also produce a negligible risk.

4.8 ASSESSMENT OF QUALITATIVE RISK FROM NO-ACTION ALTERNATIVE

An analysis of the magnitude of the source term release mechanisms, transport media, receptor points and modes of uptake at SWMU 199 has been presented in this qualitative risk assessment. A summary of this analysis is provided in Table 4.1

The concentration of plutonium (source term) in the soil at SWMU 199 appears to be very low. The concentrations are above background, but in most areas are below the CDH limit of 0.9 pCi/g (0.03 Bq/g). Release mechanisms, transport media, known receptors and modes of uptake have been evaluated, and the only completed exposure pathway is the airborne dust pathway due to soil reentrainment.

Court-ordered soil tilling and revegetation have been conducted on portions of SWMU 199 in an attempt to reduce the average plutonium concentration in soils that exceeded the 0.9 pCi/g (0.03 Bq/g) level and to stabilize the soils (Section 2.2.3). The tilling has succeeded in lowering plutonium concentrations to below CDH guidelines. Revegetation of tilled areas has been only partially successful; however, areas in which planted grasses have not been successful have developed a natural cover of opportunistic grass and weed species. While this vegetative cover is not considered adequate from a remediation standpoint, it does nonetheless provide some soil stabilization and reduce the likelihood of airborne dust reentrainment. Therefore, based on the physical parameters of SWMU 199, the nature of plutonium transport in the environment, the plutonium concentration present at SWMU 199 and the single completed exposure pathway, the magnitude of risk from a no action alternative is judged to be low to negligible.

4.9 RISK DUE TO DELAY OF IMPLEMENTING REMEDIAL ACTION

As stated in this document, plutonium movement due to precipitation and surface water runoff tends to be low due to its high affinity for the soil by adsorption. In addition, vegetative cover does exist on most contaminated lands at SWMU 199, and field sampling data indicate a gradual reduction in the plutonium concentration in the upper 0.8 in (2 cm) of soil. It is possible that this reduction is due to the plutonium becoming reentrained and blowing east, east-southeast, or south-southeast from SWMU 199. However, samplers located in these general wind directions are not detecting increased airborne plutonium activity. Therefore, this gradual decrease in soil concentration could be from the vertical downward migration of plutonium in a soil column over time. Qualitatively, human health risk to the public due to the delay in implementing remedial action is judged to be negligible.

4.10 ASSESSMENT OF REMEDY IMPLEMENTATION

Plowing and tilling will not remove the plutonium from the soils, but would dilute the concentration below the CDH plutonium-in-soil standard of 0.9 pCi/g (0.03 Bq/g). Certain precautions in performing this remedial action are mandated in the court-ordered agreement. Since generation of airborne plutonium dust is of the greatest concern, remedial action can only be performed when the following conditions are present:

- Wind velocities are no greater than 15 miles per hour (33 kilometers per hour (km/hr))
- Soil moisture greater than 15%
- Airborne plutonium contaminant levels would not exceed 0.02 pCi/m^3 (7.4 x 10^{-4} Bq/m^3)
- A fugitive dust control permit is obtained from CDH.

Inherent in the compliance with the above conditions is the necessity for water trucks to be onsite and actively wetting down the soil as remedial action proceeds at SWMU 199. A number of methods are available for prevention of plutonium exposure to site workers. Adherence to standard operating procedures, reducing fugitive dust emissions, and airborne radionuclides monitoring are established methods for reducing worker radiation exposure. Respirators can be used if engineering controls are not sufficient to provide protection for workers.

Given the fact that the required controls will prevent airborne migration of plutonium during remedial action, it is determined that the incremental risk to the public would be negligible during implementation of soil plowing and tilling, and any subsequent revegetation.

4.11 ASSESSMENT OF POST-REMEDY RISK

It has been demonstrated that soil mixing by plowing and tilling would reduce the concentration of plutonium currently on the surface of SWMU 199. Therefore, implementation of the court-mandated remedial action would reduce plutonium concentration levels in soil to levels below the CDH standard. Based on the data presented in this report, it is not clear whether the risk to the public is in fact any higher for the SWMU 199 in its present condition versus after completion of the remedial action.

4.12 POPULATIONS AT RISK OF EXPOSURE

In a quantitative risk assessment, all media-specific pathways would be quantified as to the potential exposure, and then applied to all types of populations. Commercial, residential and recreational use of the land changes the type and duration of each of these exposure pathways, and greatly affects the numerical result of the risk assessment.

The inherent uncertainty of a qualitative risk assessment does not lend itself to this type of detail when examining populations at risk and various land use scenarios. The source, pathway analysis and release mechanisms indicate airborne inhalation of fugitive dust is the only significant potential pathway. The population distribution (residential) of the 0-5 mile (0-8 kilometer) and 5-50 mile (8-80 kilometer) radius sectors from the center of the RFP is provided in Figures 4-2 and 4-3, respectively, with wind rose overlays indicating the wind directions, speeds and frequencies. The wind rose shows that the prevalent wind direction is to the east, east-southeast and south-southeast. Wind speeds range mainly from 10-50 ft/sec (3-15 m/sec), with infrequent continuous speeds above 50 ft/sec (15 m/sec). The population density east of SWMU 199 is quite low out to 5 miles (8 kilometers). This fact increases the dilution factor significantly when assessing the potential airborne exposure to a receptor.

4.13 UNCERTAINTIES IN THE RISK EVALUATION

The procedures and inputs used to assess potential human health and environmental risks in this and most such evaluations are subject to a wide variety of uncertainties. The five main sources of uncertainty are the following:

- Inadequate sample population
- Sampling and analytical methods
- Fate and transport modeling
- Exposure estimation
- Toxicological data and dose response extrapolation.

Errors associated with sampling and analysis include inherent errors in laboratory analysis, representativeness of the samples, sampling errors, and heterogeneity of the sample matrix. Although QA/QC programs serve to reduce these errors, they cannot eliminate all errors associated with sampling and analysis.

Toxicological data errors are probably the largest source of uncertainty. The EPA noted this in its guidelines for carcinogenic risk assessment:

> "There are major uncertainties in extrapolating both from animals to humans and from high to low doses. There are important species differences in uptake, metabolism, and organ distribution of carcinogens, as well as species and strain differences in large site susceptibility. Human populations are variable with respect to geographic constitution, diet, occupational and home environment, activity patterns and other cultural factors" (EPA, 1986).

The estimation of exposure requires numerous assumptions to describe the potential exposure situations. There are a number of uncertainties regarding the fate and transport of plutonium, the likelihood of exposure, the frequency of contact with contaminated media, the concentration of constituents at exposure points, and the time period of exposure. These assumptions tend to oversimplify actual site conditions. There are inherent uncertainties in determining the intake value when combined with toxicological information, to assess risk. In this qualitative assessment, specific assumptions with standardized values were used. The major assumptions used in this assessment are as follows:

- Constituent concentrations remain constant over the exposure period
- Exposure remains constant over time
- Average concentrations of constituents detected are reasonable estimates of exposure at the exposure point
- Exposed populations remain constant over the exposure period
- No dilution factor for the contaminants is offered, and they are available for 100 percent biouptake
- Risks are additive.

Table 4.2 qualitatively describes the general assumptions used in the risk assessment, and the effect on the risk assessment.

4.14 DATA NEEDS

It is evident that sufficient field data are lacking to perform an adequate quantitative risk assessment of SWMU 199. The following quantitative information would greatly increase the accuracy of any future risk assessment. Many of the parameters listed below have been quantified for the RFP as a whole; the applicability of the existing data to SWMU 199, however, has not been evaluated, and much of the existing data have not been validated. The first step in the data acquisition process, therefore, should be to evaluate the applicability of existing environmental data from the RFP to SWMU 199.

4.14.1 Physical Parameters of the Site

Soil parameters such as soil particle size, determination of soil particle size fraction with which plutonium is associated, organic content, and bulk density should be determined. Meteorological parameters such as the frequency distribution of windspeed, direction and annual stability class should be collected. Worst case soil and meteorological conditions (i.e., those conditions at the site most conducive to plutonium transport) should be identified and calculated.

4.14.2 Determination of Fugitive Dust Impact from Remedial Action

More exact information of the potential for wind erosion from bare soil, and the contribution of tilling and remedial action should be collected and evaluated.

4.14.3 Radiological Characterization

The extent and magnitude of all plutonium and americium isotopes in soil should be determined. Soil samples should be collected on smaller grids, and a standardized procedure should be made available for the quantitative risk assessment. Additional soil cores should be collected to determine the vertical migration of plutonium in the soil column. Surface runoff after a heavy rain should be collected to assess the potential for water erosion to transport plutonium. Data are available that describe plutonium-soil mixing by prairie dogs; however, the radioecology of the site has not been adequately characterized. Foliar deposition of plutonium on the vegetative cover and mat should be determined, and root samples should be collected to verify that plutonium uptake is not occurring. Insect studies should be conducted to determine if a biotic pathway up the food chain exists for plutonium. Worms and nematodes should be collected to determine if soil contact will lead to plutonium uptake or adsorption.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The review of historical information, the evaluation of the remedy effectiveness, and the baseline qualitative risk assessment developed in this document indicate the following:

- The concentration of plutonium in the soil at SWMU 199 appears to be very low. The concentrations are above background but in most areas are below the CDH limit of 0.9 pCi/g. A few land sections do exceed this limit by a factor of 2-4. However, the data that support this conclusion are suspect.

- The airborne dust pathway due to soil reentrainment is the most significant pathway that can convey plutonium to human receptors.

- The completed exposure pathways for pre-remedy, remedy implementation, and post-remedy conditions are the same at SWMU 199. If the remedy is successfully implemented, however, the concentration of plutonium available for transport as airborne dust will be reduced through tilling, and the probability of occurrence for the airborne dust pathway will be reduced through revegetation.

- Air monitoring data indicate that the control measures being used to reduce off-site impacts during remedy implementation have been effective.

- No measurable airborne impact to human receptors downwind from SWMU 199 has been observed to date.

To confirm the above conclusions, it is recommended that additional site data, including meteorological parameters, biological uptake, and air monitoring for plutonium be collected. Further soil sampling should be performed to confirm or negate conclusions concerning plutonium and americium concentrations in soil at SWMU 199. A quantitative risk assessment can then be performed to quantify the differences in potential risk to human health between the pre-remedy, remedy implementation, and post-remedy situations. These data collection activities should be integrated into future Remedial Investigation activities.

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TABLE 4.1
PROBABILITY OF OCCURRENCE AND QUALITATIVE RISK, SWMU 199, ROCKY FLATS PLANT

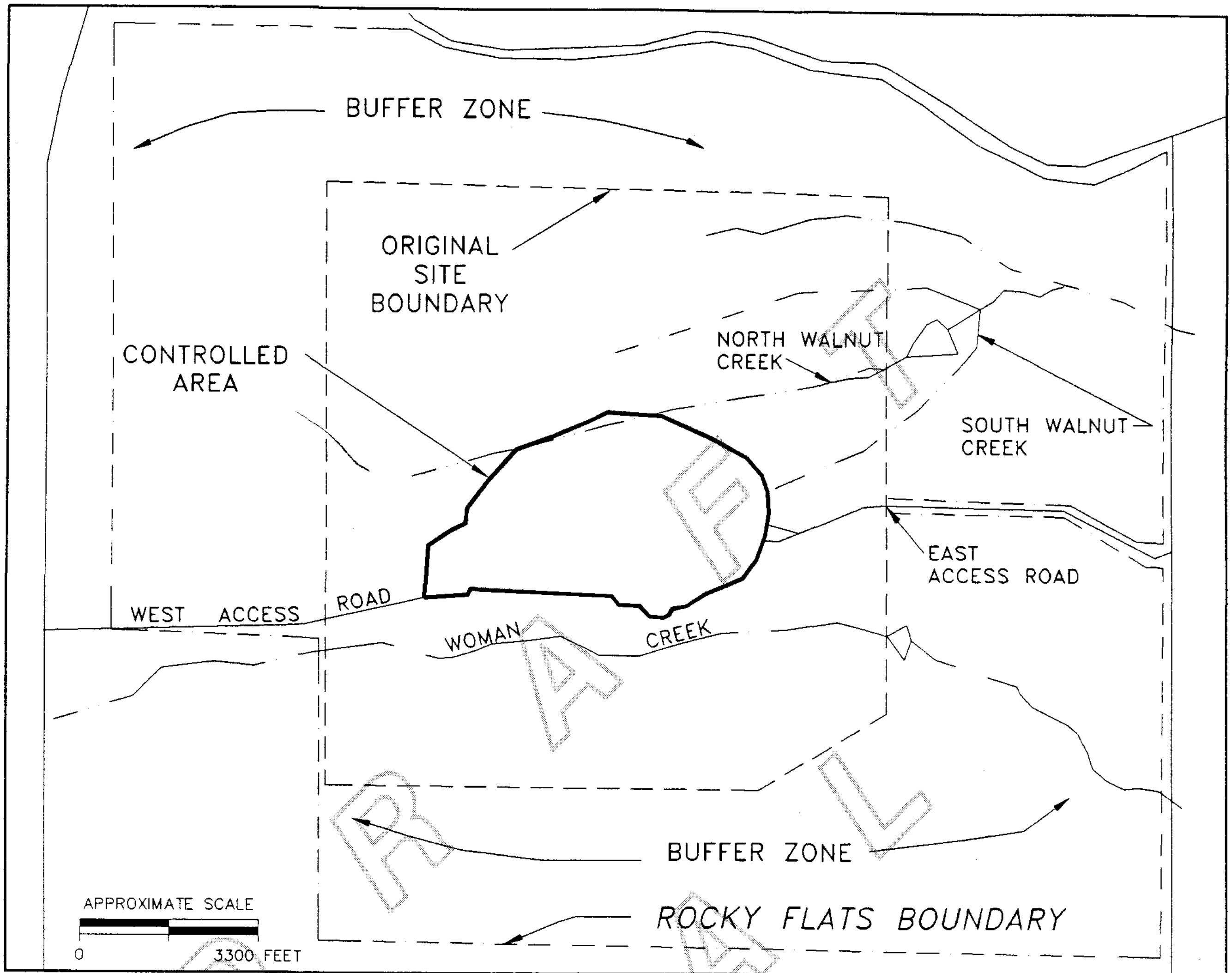
Primary Release Mechanism	Probability of Occurrence of Contaminant in Media	Secondary Source	Secondary Release Mechanism	Probability of Occurrence of Contaminant in Media	Importance to Risk Assessment	Magnitude of Qualitative Risk
Fugitive Dust	moderate-high	Air	Airborne Settled dust-plant Settled dust-soil Settled dust-water	moderate-high negligible moderate-high negligible	critical marginal marginal marginal	low-negligible negligible negligible negligible
Surface Runoff	low-moderate	Surface Water	Biotic Uptake Deposition Irrigation Infiltration Fugitive Dust	negligible negligible negligible negligible low-moderate	marginal marginal marginal marginal marginal	negligible negligible negligible negligible negligible
Infiltration/Percolation	negligible	Ground Water	Seepage Pumpage Transfer to Surface Water	negligible negligible negligible	marginal marginal marginal	negligible negligible negligible
Biotic Uptake	negligible	Biota	Biodegradation/ Percolation	negligible	marginal	negligible
Biotic Movement	negligible	Tracking by Organisms	Physical Transfer	negligible	marginal	negligible

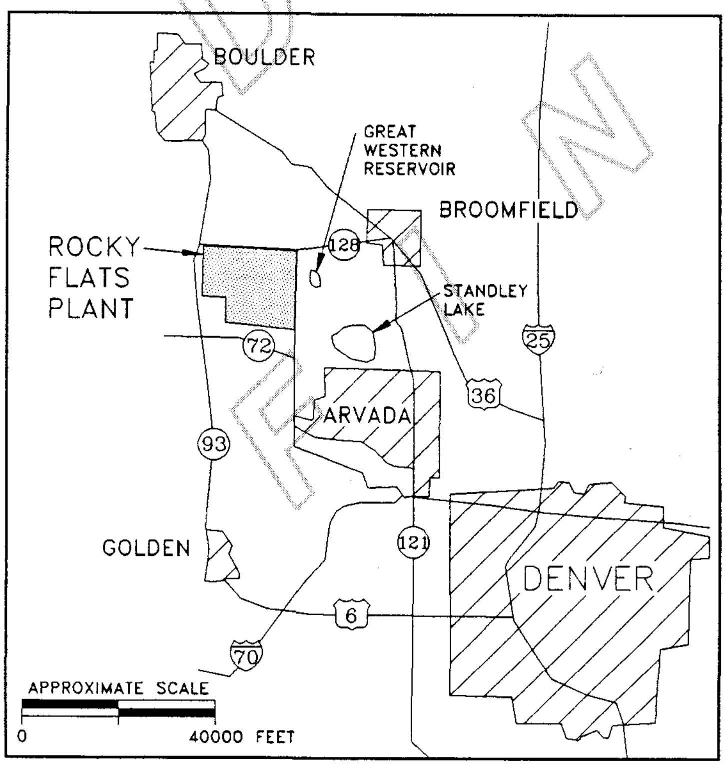
TABLE 4.2
ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION, SWMU 199, ROCKY FLATS PLANT

Assumption	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Environmental Sampling and Analysis			
Sufficient samples may not have been taken to characterize the matrices being evaluated.			Moderate
Systematic or random errors in the radiochemical analysis may yield erroneous data.			Low
Plutonium concentrations reported as "below method detection limit" are considered to be a non-detect data point.		Low	
The qualitative public health evaluation is based on the chemical of concern (Pu) only. This may represent a subset of the chemicals possible at the site.		Moderate	
Exposure Parameter Estimation			
The standard assumptions regarding body weight, period exposed, life expectancy, population characteristics, and lifestyle may not be representative for any actual exposure situation.			Moderate
The amount of media intake is assumed to be constant and representative of the exposed population.	Moderate		
Exposure to contaminants remains constant over exposure period.	Moderate		
Concentration of contaminants remains constant over exposure period.	High		
All plutonium is available for inhalation in respirable-size particles.	High		
For most contaminants all intake is assumed to come from the medium being evaluated. This does not take into account other contaminant sources such as diet, exposures occurring at locations other than the exposure point being evaluated, or other environmental media which may contribute to the intake of the chemical (i.e., relative source contribution is not accounted for).		Moderate	

TABLE 4.2
ASSUMPTIONS AND THEIR EFFECTS ON RISK ESTIMATION,
SWMU 199, ROCKY FLATS PLANT
(continued)

Assumption	Effect on Risk		
	May Over-Estimate Risk	May Under-Estimate Risk	May Over/ Under-Estimate Risk
Environmental Parameter Measurement			
Food does not contribute to plutonium uptake.		Moderate	
Dermal absorption of plutonium from soil is negligible.		Low	
Toxicological Data			
Risks are assumed to be additive. Risks may not be additive because of synergistic or antagonistic actions or other chemicals.			Moderate
Assumes absorption is equivalent across species. This is implicit in the derivation of the acceptable intakes or cancer slope factors in this assessment.			Low
Extrapolation of toxicity data from species to species, and from laboratory animals to animals in the field.			Moderate





DRAWN BY	KRONER 10/4/90		
CHECKED BY	CJR	10-18-90	DRAWING NUMBER 304923-A6
APPROVED BY	TDK	10-18-90	

FIGURE 1-1

ROCKY FLATS LOCATION MAP

ADAPTED FROM: FIG. 1-1, E.G. & G. DRAFT GEOLOGIC CHARACTERIZATION REPORT, JAN. 3, 1990.

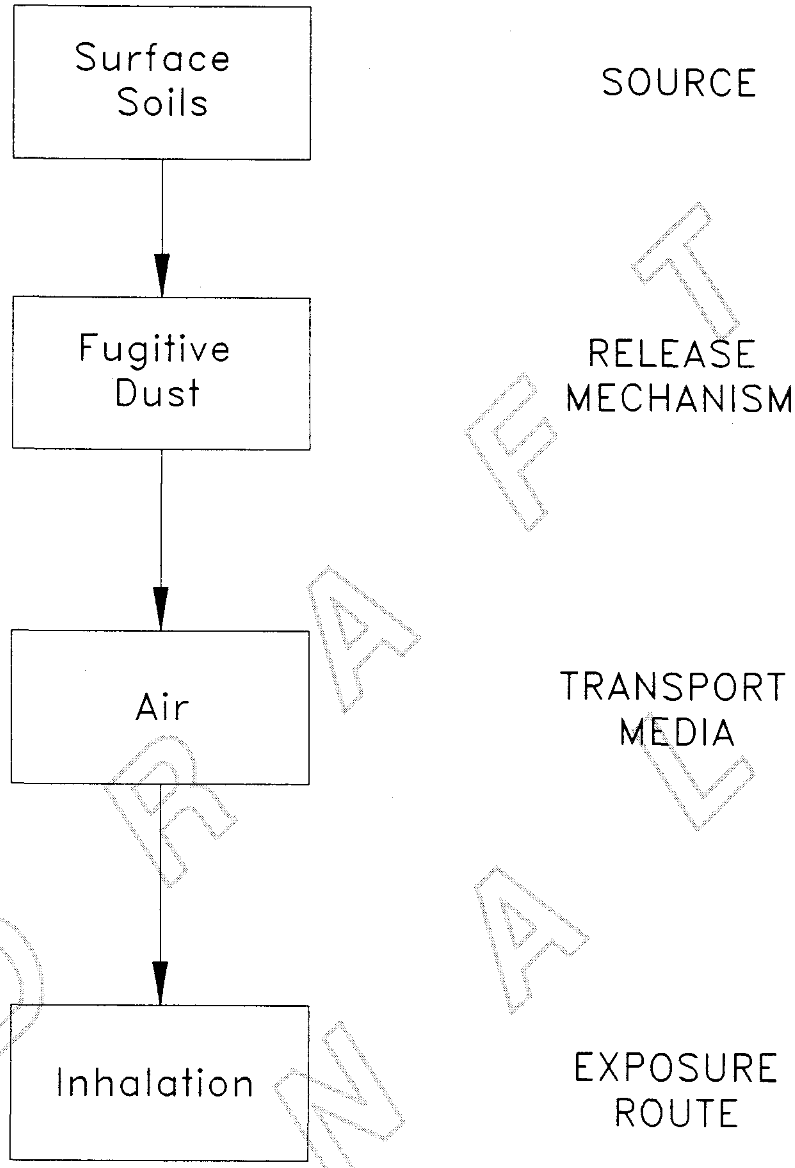
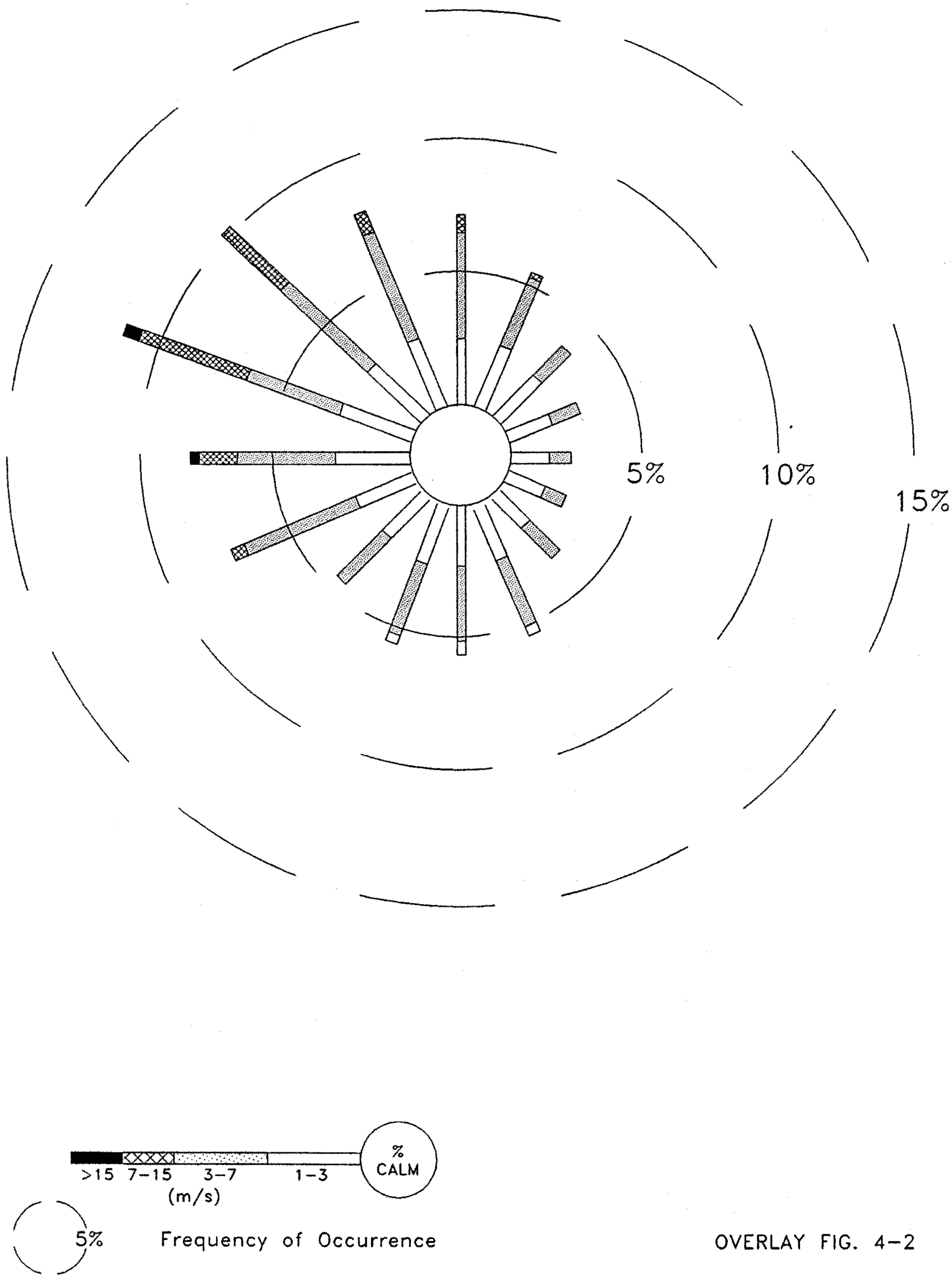


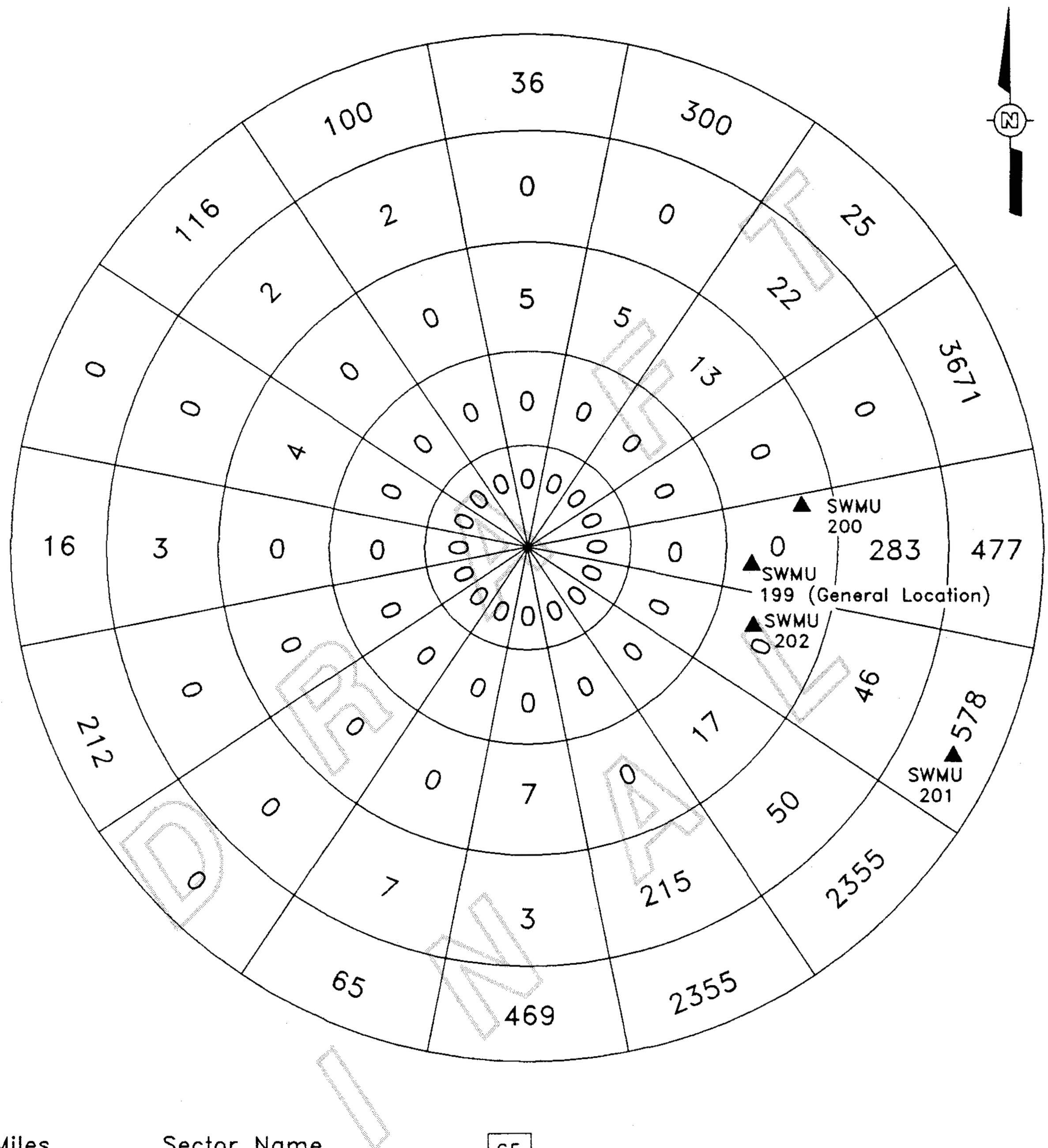
FIGURE 4–1

COMPLETED EXPOSURE PATHWAYS,
SWMU 199
QUALITATIVE RISK ASSESSMENT

DRAWN BY	KRONER	CHECKED BY	CJR	10-16-90
	8/17/90	APPROVED BY	TDK	10-16-90
DRAWING NUMBER	304923-A2			



OVERLAY FIG. 4-2



Miles	Sector Name
0–1	Sector 1
1–2	Sector 2
2–3	Sector 3
3–4	Sector 4
4–5	Sector 5

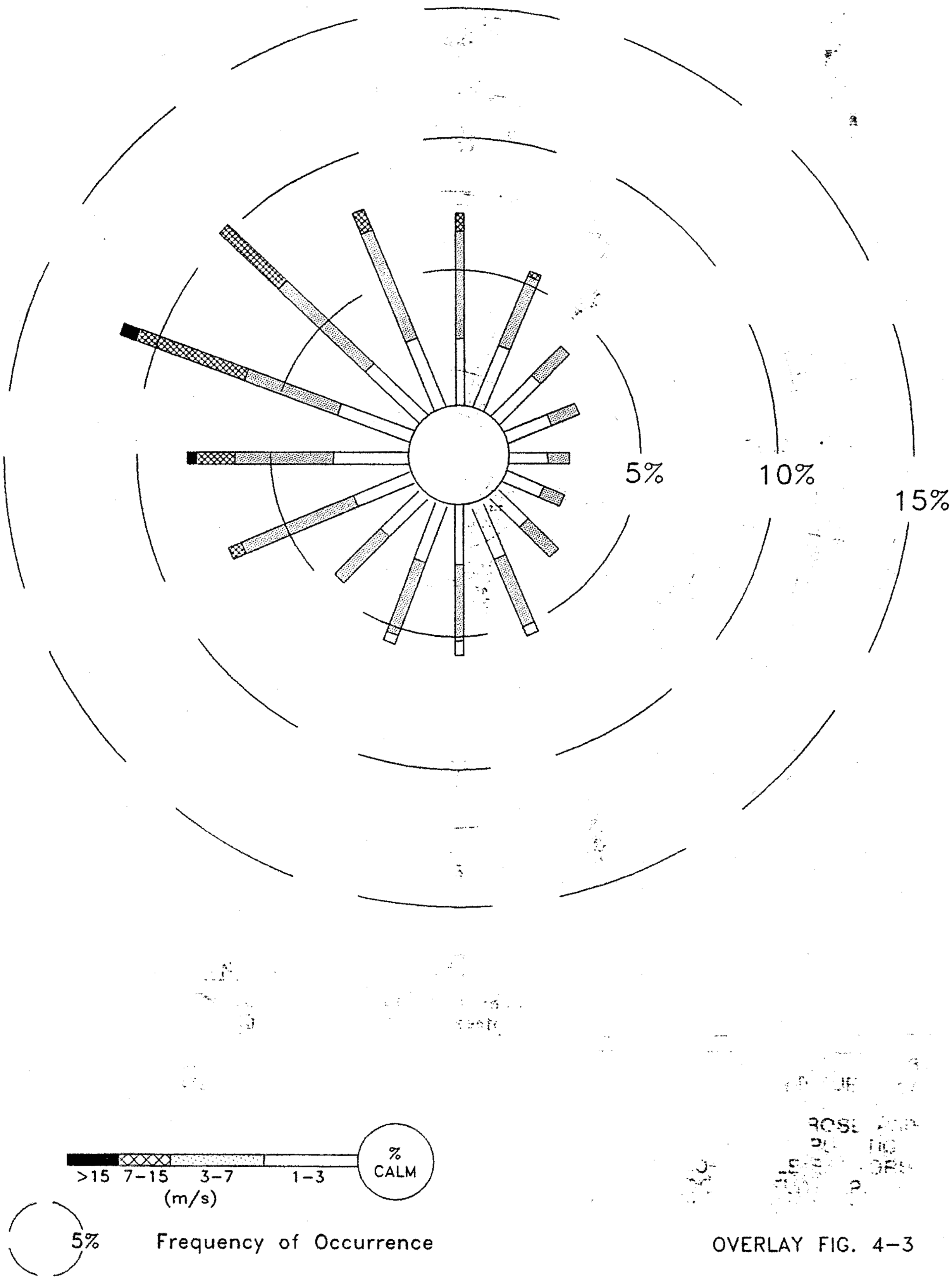
$\boxed{65}$ Number of persons living in sector

FIGURE 4-2

WIND ROSE AND 1989 POPULATION, 0-5 MILE SECTORS, ROCKY FLATS PLANT

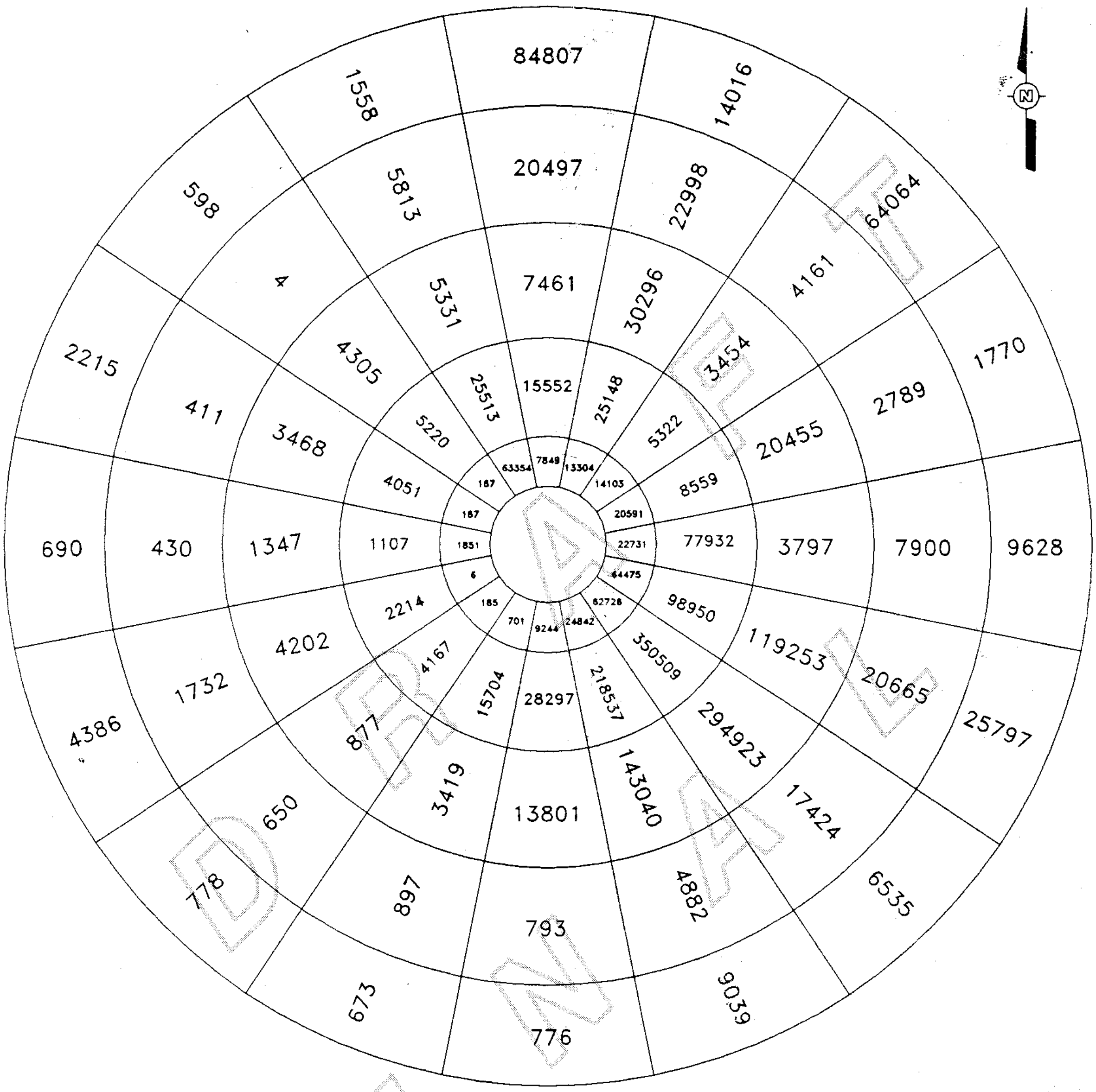
REFERENCE: FIGURE 2-1, DOE, 1989 POPULATION, ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT.

DRAWN BY	KRONER 8/24/90	CHECKED BY / APPROVED BY	CJR / TDK	10-16-90 / 10-16-90	DRAWING NUMBER	304923-A4



OVERLAY FIG. 4–3

DRAWN BY	KRONER 8/24/90
CHECKED BY	CJR 10-16-90
APPROVED BY	TDK 10-16-90
DRAWING NUMBER	304923-A3



Miles	Sector Name
5–10	Sector 10
10–20	Sector 20
20–30	Sector 30
30–40	Sector 40
40–50	Sector 50

65 Number of persons living in sector

FIGURE 4-3

WIND ROSE AND 1989 POPULATION, 10-50 MILE SECTORS, ROCKY FLATS PLANT

REFERENCE: FIGURE 2-4, DOE, 1989 POPULATION, ECONOMIC AND LAND USE DATA BASE FOR ROCKY FLATS PLANT.

DRAWN BY	KRONER 8/24/90	CHECKED BY	CJR		DRAWING NUMBER	304923-B3
		APPROVED BY	TDK			

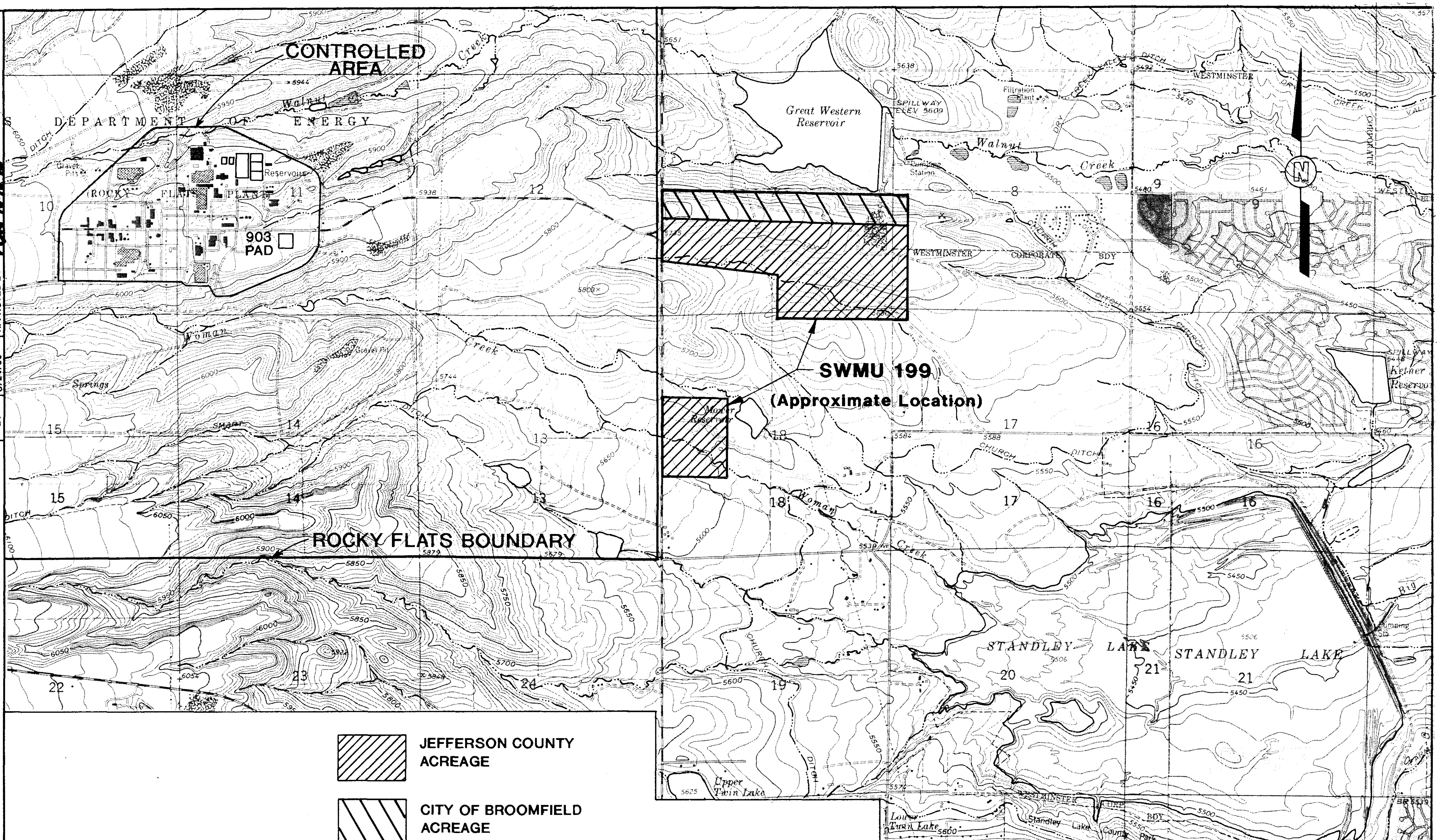


Figure 2-1

SWMU 199 Location Map

DRAWN BY	KRONER 8/10/90	CHECKED BY	CJA	10-16-90	DRAWING NUMBER	304923-B1
		APPROVED BY	TDK	10-16-90		

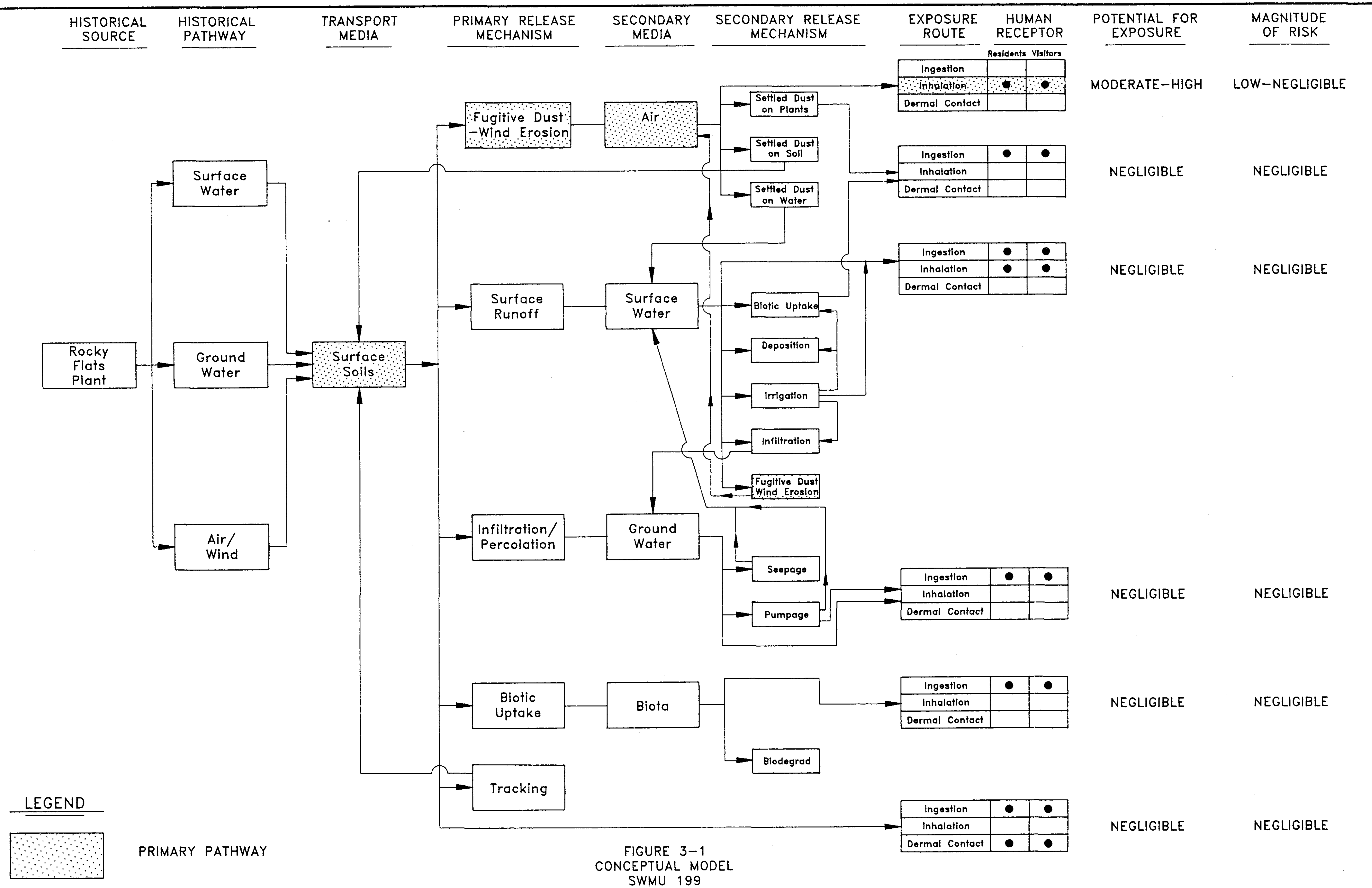


FIGURE 3-1
CONCEPTUAL MODEL
SWMU 199
CONTAMINATED SOILS

4923B1

DRAFT